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PATENT COOPERATION TREATY

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INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference PHN 17.510WO	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/EP 00/05906	International filing date *(day/month/year)* 26/06/2000	(Earliest) Priority Date *(day/month/year)* 29/06/1999
Applicant KONINKLIJKE PHILIPS ELECTRONICS N.V.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

      [ ] contained in the international application in written form.
      [ ] filed together with the international application in computer readable form.
      [ ] furnished subsequently to this Authority in written form.
      [ ] furnished subsequently to this Authority in computer readble form.
      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title**,

   [ ] the text is approved as submitted by the applicant.
   [X] the text has been established by this Authority to read as follows:

   SYNCHRONISATION CODEWORD FOR INTERFERENCE REDUCTION IN A CDMA SYSTEM

5. With regard to the **abstract**,

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

   [X] as suggested by the applicant.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 00/05906

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B1/707

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, PAJ, INSPEC, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 97 31429 A (LOCKHEED CORP) 28 August 1997 (1997-08-28) abstract page 3, line 14 - line 25 page 10, line 37 -page 1, line 36; figure 1 ---	1-9
A	US 5 499 236 A (GREENWOOD KENNETH C ET AL) 12 March 1996 (1996-03-12) cited in the application abstract; claims 1,16-18 ---	1-9
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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Date of the actual completion of the international search	Date of mailing of the international search report
27 October 2000	07/11/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ó Donnabháin, E

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	BOTTOMLEY G E: "SIGNATURE SEQUENCE SELECTION IN A CDMA SYSTEM WITH ORTHOGONAL CODING" IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY,US,IEEE INC. NEW YORK, vol. 42, no. 1, 1 February 1993 (1993-02-01), pages 62-68, XP000363400 ISSN: 0018-9545 abstract page 62, column 1 -column 2 -----	1-9

1

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Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9731429 A	28-08-1997	US 5825835 A	20-10-1998
		AU 1964697 A	10-09-1997
		BR 9707685 A	04-01-2000
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		EP 0882330 A	09-12-1998
US 5499236 A	12-03-1996	AU 698991 B	19-11-1998
		AU 3327695 A	07-03-1996
		CA 2197757 A	22-02-1996
		DE 69515884 D	27-04-2000
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		EP 0776556 A	04-06-1997
		JP 10504154 T	14-04-1998
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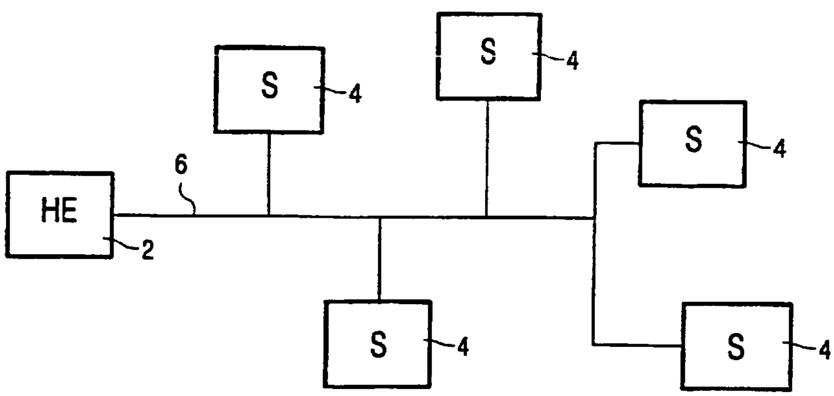
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: SYNCHRONISATION CODEWORD FOR INTERFERENCE REDUCTION IN A CDMA SYSTEM



(57) **Abstract:** The CDMA communication system according to the invention comprises at least one primary station (2) and a plurality of secondary stations (4). The primary station (2) and the secondary stations (4) can exchange CDMA signals (18) via a communication medium (6). The secondary stations (4) each comprise a modulator (10) for modulating data signals (16) with code words (14) in order to obtain the CDMA signals (18). A modulator (10) of a secondary station (4) initially modulates its data signal (16) with an initial code word until that secondary station (4) is synchronised with the primary station (2). From that moment on the data signal (16) is modulated with a final code word. Ideally, an initial code word is used which is, for every possible time shift of that code, substantially orthogonal to all the final code words in use by the already synchronised secondary stations (4). Such an initial code word does not interfere with the CDMA signals (18) received and transmitted by the already synchronised secondary stations (4) and is therefore very well suited for the purpose of synchronising a secondary station (4) with the primary station (2). If Walsh-Hadamard codes are used as code words the code word corresponding to the first row of the Walsh-Hadamard matrix is an example of such an ideal initial code word.

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SYNCHRONISATION CODEWORD FOR INTERFERENCE REDUCTION IN A CDMA SYSTEM

The invention relates to a CDMA communication system comprising at least one primary station and a plurality of secondary stations, the primary station and the secondary stations exchanging CDMA signals via a communication medium, the secondary stations each comprising a modulator for modulating a respective data signal with a respective code word in order to obtain a respective CDMA signal, the modulator being embodied so as to modulate the respective data signal with an initial code word until synchronisation with the primary station is obtained, the modulator being further embodied so as to modulate the respective data signal with a respective final code word after synchronisation with the primary station has been obtained.

The invention further relates to a secondary station for exchanging CDMA signals via a communication medium with at least one primary station and to a method of synchronising a secondary station with a primary station.

A CDMA communication system according to the preamble is known from United States Patent Number 5 499 236. Code Division Multiple Access (CDMA) is a multiplexing technique which permits a number of users to simultaneously access a transmission channel. For this purpose a data signal to be transmitted is modulated with a code word, i.e. a pseudorandom binary sequence, in order to spread the spectrum of the waveform. In a receiver the original data signal can be detected by correlating the received CDMA signal with the corresponding code word. This correlation despreads the spectrum. Other CDMA signals are not despread by the correlator because their code words do not match. CDMA can be used, for example, in mobile communication systems and in interactive cable television networks.

The system capacity, i.e. the total sum of the bit rates of the users, of a synchronised CDMA communication system is limited by the maximum number of different code words, whereas the system capacity of an asynchronous CDMA communication system is limited by the interference noise. Hence, the system capacity of a synchronised CDMA

communication system is generally much higher than that of an asynchronous CDMA communication system.

In the known synchronised CDMA communication system all secondary stations which are not yet synchronised with the primary station and which want to transmit data to that primary station use the same initial code word to modulate their data signals with. Next, the resulting asynchronous CDMA signals are transmitted to the primary station. The primary station then determines for each secondary station the timing difference between the received CDMA signal and a reference clock and transmits this timing difference to each particular secondary station. Next, the secondary stations can synchronise with the primary station by time shifting the initial code word in accordance with the received timing differences. This process is repeated for each secondary station until synchronisation is obtained, after which a different final code word is used by each secondary station to modulate its data signal with.

In the known CDMA communication system the asynchronous use of the initial code word may cause interference with the CDMA signals received and transmitted by the already synchronised secondary stations.

An object of the invention is to provide a CDMA communication system, wherein the asynchronous use of the initial code word does not cause interference with the CDMA signals received and transmitted by the already synchronised secondary stations. This object is achieved in the CDMA communication system according to the invention, which is characterized in that the initial code word is substantially orthogonal to the final code words for every possible time shift of the initial code word. The invention is based upon the recognition that such an initial code word does not interfere with the CDMA signals received and transmitted by the already synchronised secondary stations and is therefore very well suited for the purpose of synchronising a secondary station with the primary station.

A first embodiment of the CDMA communication system according to the invention is characterized in that all symbol values of the initial code word are equal to each other. If all symbol values of an initial code word are equal to each other, that initial code word remains the same for every possible time shift of that initial code word. Hence, a time shift of that initial code word does not influence the orthogonality of that initial code word relative to the final code words.

A second embodiment of the CDMA communication system according to the invention is characterized in that the code words are Walsh-Hadamard codes and that the initial code word corresponds to the first row or the first column of the Walsh-Hadamard matrix. Walsh-Hadamard code words have ideal cross correlation properties because all the Walsh-Hadamard code words are mutually orthogonal. The system capacity of a synchronised CDMA communication system can be further increased by using Walsh-Hadamard code words. If Walsh-Hadamard codes are used as code words the code corresponding to the first row or the first column of the Walsh-Hadamard matrix is an ideal initial code word as it is, for every possible time shift of that code, substantially orthogonal to all the final Walsh-Hadamard code words in use by the already synchronised secondary stations.

The above object and features of the present invention will be more apparent from the following description of the preferred embodiments with reference to the drawings, wherein:

Figure 1 shows a block diagram of an embodiment of a CDMA communication system according to the invention,

Figure 2 shows a block diagram of part of an embodiment of a secondary station,

Figure 3 shows a Walsh-Hadamard matrix H_4.

Figure 1 shows a block diagram of an embodiment of a CDMA communication system according to the invention. In such a CDMA communication system CDMA signals are exchanged via a communication medium 6 between a number of stations 2 and 4. These CDMA communication stations 2 and 4 comprise at least one primary station 2, which is here a head end, and a plurality of secondary stations 4. The CDMA communication system, which may comprise further primary stations 2 and secondary stations 4, is a partly synchronised CDMA communication system. This means that some of the secondary stations 4 are synchronised to the primary station 2, while other secondary stations 4 are not yet synchronised to the primary station 2.

Figure 2 shows a block diagram of a part of a secondary station 4. The part that is shown is that relating to the modulation of an input data signal 16. Operational parameters of all blocks shown are controlled by a controller (not shown). The secondary stations 4 each

comprise a modulator 10 for modulating the input data signals 16 with code words 14 in order to obtain the CDMA signals 18. These code words 14 may be generated by a generator 12. A modulator 10 of a secondary station 4 which is not yet synchronised to the primary station 2 initially modulates its data signal 16 with an initial code word 14 until that secondary station 4 is synchronised with the primary station 2. From that moment on the data signal 16 is modulated with a final code word 14.

Ideally, an initial code word 14 is used which is, for every possible time shift of that code, substantially orthogonal to all the final code words 14 in use by the already synchronised secondary stations 4. Such an initial code word does not interfere with the CDMA signals 18 received and transmitted by the already synchronised secondary stations 4 and is therefore very well suited for the purpose of synchronising a secondary station 4 with the primary station 2. Code words 14 which have symbol values which are all equal to each other are such ideal initial code words. If all symbol values of an initial code word are equal to each other, that initial code word remains the same for every possible time shift of that initial code word. Hence, a time shift of that initial code word does not influence the orthogonality of that initial code word relative to the final code words. If Walsh-Hadamard codes are used as code words 14 the code word corresponding to the first row or the first column of the Walsh-Hadamard matrix is a practical example of an ideal initial code word having symbol values which are all equal to each other.

Figure 3 shows a Walsh-Hadamard matrix H_4. A Walsh-Hadamard matrix H_n is defined inductively and can be calculated from a given Walsh-Hadamard matrix H_1. The rows $R_0..R_{2^n-1}$ and columns $C_0..C_{2^n-1}$ of a Walsh-Hadamard matrix H_n are orthogonal. The code words 14 may be based on the rows $R_0..R_{2^n-1}$ or the columns $C_0..C_{2^n-1}$ of such a Walsh-Hadamard matrix H_n. A code word based upon the first row R_0 or the first column C_0 of the Walsh-Hadamard matrix H_4 (in general: of the Walsh-Hadamard matrix H_n) has symbol values which are all equal to each other.

The scope of the invention is not limited to the embodiments explicitly disclosed. The invention is embodied in each new characteristic and each combination of characteristics. Any reference signs do not limit the scope of the claims. The word "comprising" does not exclude the presence of other elements or steps than those listed in a claim. Use of the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.

CLAIMS:

1. A CDMA communication system comprising at least one primary station (2) and a plurality of secondary stations (4), the primary station (2) and the secondary stations (4) exchanging CDMA signals (18) via a communication medium (6), the secondary stations (4) each comprising a modulator (10) for modulating a respective data signal (16) with a respective code word (14) in order to obtain a respective CDMA signal (18), the modulator (10) being embodied so as to modulate the respective data signal (16) with an initial code word until synchronisation with the primary station (2) is obtained, the modulator (10) being further embodied so as to modulate the respective data signal (16) with a respective final code word after synchronisation with the primary station (2) has been obtained, characterized in that the initial code word is substantially orthogonal to the final code words for every possible time shift of the initial code word.

2. A CDMA communication system according to Claim 1, characterized in that all symbol values of the initial code word are equal to each other.

3. A CDMA communication system according to Claim 1 or 2, characterized in that the code words (14) are Walsh-Hadamard codes and that the initial code word corresponds to the first row or the first column of the Walsh-Hadamard matrix.

4. A secondary station (4) for exchanging CDMA signals (18) via a communication medium (6) with at least one primary station (2), the secondary station (4) comprising a modulator (10) for modulating a data signal (16) with a code word (14) in order to obtain a CDMA signal (18), the modulator (10) being embodied so as to modulate the data signal (16) with an initial code word until synchronisation with the primary station (2) is obtained, the modulator (10) being further embodied so as to modulate the data signal (16) with a final code word after synchronisation with the primary station (2) has been obtained, characterized in that the initial code word is substantially orthogonal to the final code word for every possible time shift of the initial code word.

5. A secondary station (4) according to Claim 4, characterized in that all symbol values of the initial code word are equal to each other.

6. A secondary station (4) according to Claim 4 or 5, characterized in that the code words (14) are Walsh-Hadamard codes and that the initial code word corresponds to the first row or the first column of the Walsh-Hadamard matrix.

7. A method of synchronising a secondary station (4) with a primary station (2), the primary station (2) and the secondary station (4) exchanging CDMA signals (18) via a communication medium (6), the method comprising the steps of:
- modulating a data signal (16) with an initial code word (14) in order to obtain an initial CDMA signal (18) and transmitting the initial CDMA signal (18) to the primary station (2) until synchronisation with the primary station (2) is obtained,
- modulating the data signal (16) with a final code word (14) in order to obtain a final CDMA signal (18) and transmitting the final CDMA signal (18) after synchronisation with the primary station (2) has been obtained,
characterized in that the initial code word is substantially orthogonal to the final code word for every possible time shift of the initial code word.

8. A method of synchronising a secondary station (4) with a primary station (2) according to Claim 7, characterized in that all symbol values of the initial code word are equal to each other.

9. A method of synchronising a secondary (4) station with a primary station (2) according to Claim 7 or 8, characterized in that the code words (14) are Walsh-Hadamard codes and that the initial code word corresponds to the first row or the first column of the Walsh-Hadamard matrix.

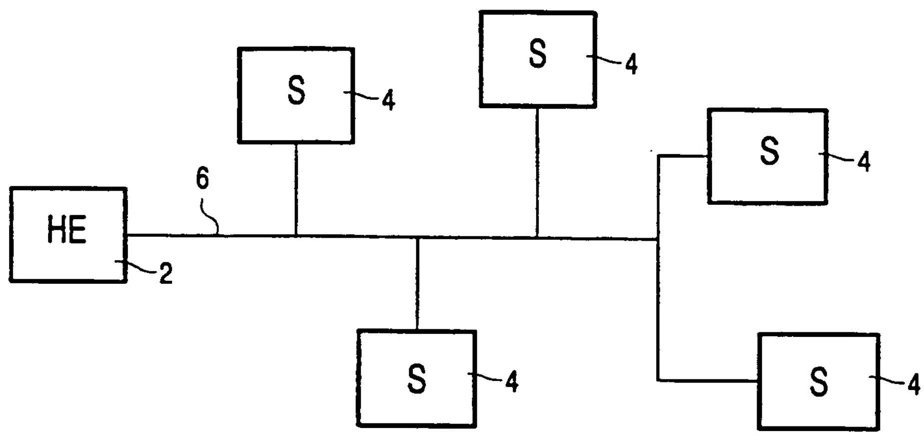

FIG. 1

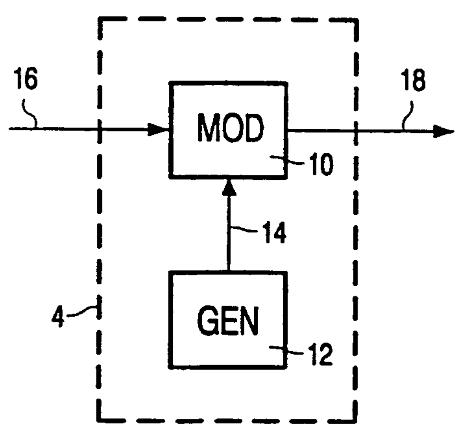

FIG. 2

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
R_0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R_1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
R_2	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
R_3	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
R_4	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
R_5	0	1	0	1	1	0	1	0	0	1	0	1	1	0	1	0
R_6	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
R_7	0	1	1	0	1	0	0	1	0	1	1	0	1	0	0	1
R_8	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
R_9	0	1	0	1	0	1	0	1	1	0	1	0	1	0	1	0
R_{10}	0	0	1	1	0	0	1	1	1	1	0	0	1	1	0	0
R_{11}	0	1	1	0	0	1	1	0	1	0	0	1	1	0	0	1
R_{12}	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
R_{13}	0	1	0	1	1	0	1	0	1	0	1	0	0	1	0	1
R_{14}	0	0	1	1	1	1	0	0	1	1	0	0	0	0	1	1
R_{15}	0	1	1	0	1	0	0	1	1	0	0	1	0	1	1	0

FIG. 3

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
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B. FIELDS SEARCHED

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ó Donnabháin, E

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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1

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(71) Applicant *(for all designated States except US)*: **KONINKLIJKE PHILIPS ELECTRONICS N.V.** [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(72) Inventors; and
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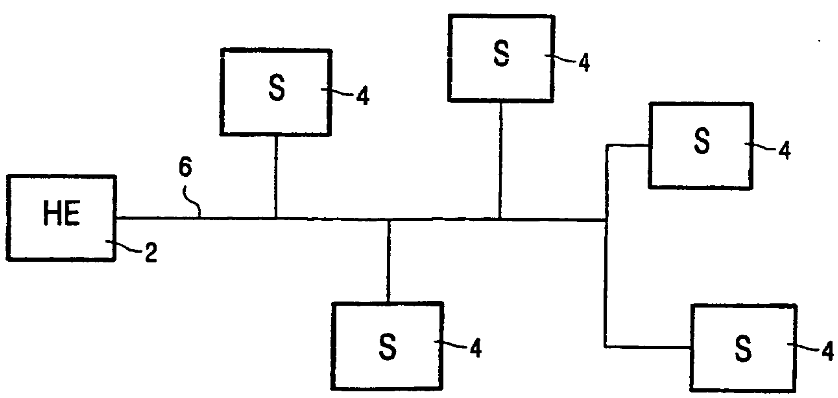
(54) Title: SYNCHRONISATION CODEWORD FOR INTERFERENCE REDUCTION IN A CDMA SYSTEM



(57) Abstract: The CDMA communication system according to the invention comprises at least one primary station (2) and a plurality of secondary stations (4). The primary station (2) and the secondary stations (4) can exchange CDMA signals (18) via a communication medium (6). The secondary stations (4) each comprise a modulator (10) for modulating data signals (16) with code words (14) in order to obtain the CDMA signals (18). A modulator (10) of a secondary station (4) initially modulates its data signal (16) with an initial code word until that secondary station (4) is synchronised with the primary station (2). From that moment on the data signal (16) is modulated with a final code word. Ideally, an initial code word is used which is, for every possible time shift of that code, substantially orthogonal to all the final code words in use by the already synchronised secondary stations (4). Such an initial code word does not interfere with the CDMA signals (18) received and transmitted by the already synchronised secondary stations (4) and is therefore very well suited for the purpose of synchronising a secondary station (4) with the primary station (2). If Walsh-Hadamard codes are used as code words the code word corresponding to the first row of the Walsh-Hadamard matrix is an example of such an ideal initial code word.

WO 01/01593 A1

SYNCHRONISATION CODEWORD FOR INTERFERENCE REDUCTION IN A CDMA SYSTEM

The invention relates to a CDMA communication system comprising at least one primary station and a plurality of secondary stations, the primary station and the secondary stations exchanging CDMA signals via a communication medium, the secondary stations each comprising a modulator for modulating a respective data signal with a respective code word in order to obtain a respective CDMA signal, the modulator being embodied so as to modulate the respective data signal with an initial code word until synchronisation with the primary station is obtained, the modulator being further embodied so as to modulate the respective data signal with a respective final code word after synchronisation with the primary station has been obtained.

The invention further relates to a secondary station for exchanging CDMA signals via a communication medium with at least one primary station and to a method of synchronising a secondary station with a primary station.

A CDMA communication system according to the preamble is known from United States Patent Number 5 499 236. Code Division Multiple Access (CDMA) is a multiplexing technique which permits a number of users to simultaneously access a transmission channel. For this purpose a data signal to be transmitted is modulated with a code word, i.e. a pseudorandom binary sequence, in order to spread the spectrum of the waveform. In a receiver the original data signal can be detected by correlating the received CDMA signal with the corresponding code word. This correlation despreads the spectrum. Other CDMA signals are not despread by the correlator because their code words do not match. CDMA can be used, for example, in mobile communication systems and in interactive cable television networks.

The system capacity, i.e. the total sum of the bit rates of the users, of a synchronised CDMA communication system is limited by the maximum number of different code words, whereas the system capacity of an asynchronous CDMA communication system is limited by the interference noise. Hence, the system capacity of a synchronised CDMA

communication system is generally much higher than that of an asynchronous CDMA communication system.

In the known synchronised CDMA communication system all secondary stations which are not yet synchronised with the primary station and which want to transmit data to that primary station use the same initial code word to modulate their data signals with. Next, the resulting asynchronous CDMA signals are transmitted to the primary station. The primary station then determines for each secondary station the timing difference between the received CDMA signal and a reference clock and transmits this timing difference to each particular secondary station. Next, the secondary stations can synchronise with the primary station by time shifting the initial code word in accordance with the received timing differences. This process is repeated for each secondary station until synchronisation is obtained, after which a different final code word is used by each secondary station to modulate its data signal with.

In the known CDMA communication system the asynchronous use of the initial code word may cause interference with the CDMA signals received and transmitted by the already synchronised secondary stations.

An object of the invention is to provide a CDMA communication system, wherein the asynchronous use of the initial code word does not cause interference with the CDMA signals received and transmitted by the already synchronised secondary stations. This object is achieved in the CDMA communication system according to the invention, which is characterized in that the initial code word is substantially orthogonal to the final code words for every possible time shift of the initial code word. The invention is based upon the recognition that such an initial code word does not interfere with the CDMA signals received and transmitted by the already synchronised secondary stations and is therefore very well suited for the purpose of synchronising a secondary station with the primary station.

A first embodiment of the CDMA communication system according to the invention is characterized in that all symbol values of the initial code word are equal to each other. If all symbol values of an initial code word are equal to each other, that initial code word remains the same for every possible time shift of that initial code word. Hence, a time shift of that initial code word does not influence the orthogonality of that initial code word relative to the final code words.

A second embodiment of the CDMA communication system according to the invention is characterized in that the code words are Walsh-Hadamard codes and that the initial code word corresponds to the first row or the first column of the Walsh-Hadamard matrix. Walsh-Hadamard code words have ideal cross correlation properties because all the Walsh-Hadamard code words are mutually orthogonal. The system capacity of a synchronised CDMA communication system can be further increased by using Walsh-Hadamard code words. If Walsh-Hadamard codes are used as code words the code corresponding to the first row or the first column of the Walsh-Hadamard matrix is an ideal initial code word as it is, for every possible time shift of that code, substantially orthogonal to all the final Walsh-Hadamard code words in use by the already synchronised secondary stations.

The above object and features of the present invention will be more apparent from the following description of the preferred embodiments with reference to the drawings, wherein:

Figure 1 shows a block diagram of an embodiment of a CDMA communication system according to the invention,

Figure 2 shows a block diagram of part of an embodiment of a secondary station,

Figure 3 shows a Walsh-Hadamard matrix H_4.

Figure 1 shows a block diagram of an embodiment of a CDMA communication system according to the invention. In such a CDMA communication system CDMA signals are exchanged via a communication medium 6 between a number of stations 2 and 4. These CDMA communication stations 2 and 4 comprise at least one primary station 2, which is here a head end, and a plurality of secondary stations 4. The CDMA communication system, which may comprise further primary stations 2 and secondary stations 4, is a partly synchronised CDMA communication system. This means that some of the secondary stations 4 are synchronised to the primary station 2, while other secondary stations 4 are not yet synchronised to the primary station 2.

Figure 2 shows a block diagram of a part of a secondary station 4. The part that is shown is that relating to the modulation of an input data signal 16. Operational parameters of all blocks shown are controlled by a controller (not shown). The secondary stations 4 each

comprise a modulator 10 for modulating the input data signals 16 with code words 14 in order to obtain the CDMA signals 18. These code words 14 may be generated by a generator 12. A modulator 10 of a secondary station 4 which is not yet synchronised to the primary station 2 initially modulates its data signal 16 with an initial code word 14 until that secondary station 4 is synchronised with the primary station 2. From that moment on the data signal 16 is modulated with a final code word 14.

Ideally, an initial code word 14 is used which is, for every possible time shift of that code, substantially orthogonal to all the final code words 14 in use by the already synchronised secondary stations 4. Such an initial code word does not interfere with the CDMA signals 18 received and transmitted by the already synchronised secondary stations 4 and is therefore very well suited for the purpose of synchronising a secondary station 4 with the primary station 2. Code words 14 which have symbol values which are all equal to each other are such ideal initial code words. If all symbol values of an initial code word are equal to each other, that initial code word remains the same for every possible time shift of that initial code word. Hence, a time shift of that initial code word does not influence the orthogonality of that initial code word relative to the final code words. If Walsh-Hadamard codes are used as code words 14 the code word corresponding to the first row or the first column of the Walsh-Hadamard matrix is a practical example of an ideal initial code word having symbol values which are all equal to each other.

Figure 3 shows a Walsh-Hadamard matrix H_4. A Walsh-Hadamard matrix H_n is defined inductively and can be calculated from a given Walsh-Hadamard matrix H_1. The rows $R_0..R_{2^n-1}$ and columns $C_0..C_{2^n-1}$ of a Walsh-Hadamard matrix H_n are orthogonal. The code words 14 may be based on the rows $R_0..R_{2^n-1}$ or the columns $C_0..C_{2^n-1}$ of such a Walsh-Hadamard matrix H_n. A code word based upon the first row R_0 or the first column C_0 of the Walsh-Hadamard matrix H_4 (in general: of the Walsh-Hadamard matrix H_n) has symbol values which are all equal to each other.

The scope of the invention is not limited to the embodiments explicitly disclosed. The invention is embodied in each new characteristic and each combination of characteristics. Any reference signs do not limit the scope of the claims. The word "comprising" does not exclude the presence of other elements or steps than those listed in a claim. Use of the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements.

CLAIMS:

1. A CDMA communication system comprising at least one primary station (2) and a plurality of secondary stations (4), the primary station (2) and the secondary stations (4) exchanging CDMA signals (18) via a communication medium (6), the secondary stations (4) each comprising a modulator (10) for modulating a respective data signal (16) with a respective code word (14) in order to obtain a respective CDMA signal (18), the modulator (10) being embodied so as to modulate the respective data signal (16) with an initial code word until synchronisation with the primary station (2) is obtained, the modulator (10) being further embodied so as to modulate the respective data signal (16) with a respective final code word after synchronisation with the primary station (2) has been obtained, characterized in that the initial code word is substantially orthogonal to the final code words for every possible time shift of the initial code word.

2. A CDMA communication system according to Claim 1, characterized in that all symbol values of the initial code word are equal to each other.

3. A CDMA communication system according to Claim 1 or 2, characterized in that the code words (14) are Walsh-Hadamard codes and that the initial code word corresponds to the first row or the first column of the Walsh-Hadamard matrix.

4. A secondary station (4) for exchanging CDMA signals (18) via a communication medium (6) with at least one primary station (2), the secondary station (4) comprising a modulator (10) for modulating a data signal (16) with a code word (14) in order to obtain a CDMA signal (18), the modulator (10) being embodied so as to modulate the data signal (16) with an initial code word until synchronisation with the primary station (2) is obtained, the modulator (10) being further embodied so as to modulate the data signal (16) with a final code word after synchronisation with the primary station (2) has been obtained, characterized in that the initial code word is substantially orthogonal to the final code word for every possible time shift of the initial code word.

5. A secondary station (4) according to Claim 4, characterized in that all symbol values of the initial code word are equal to each other.

6. A secondary station (4) according to Claim 4 or 5, characterized in that the code words (14) are Walsh-Hadamard codes and that the initial code word corresponds to the first row or the first column of the Walsh-Hadamard matrix.

7. A method of synchronising a secondary station (4) with a primary station (2), the primary station (2) and the secondary station (4) exchanging CDMA signals (18) via a communication medium (6), the method comprising the steps of:
- modulating a data signal (16) with an initial code word (14) in order to obtain an initial CDMA signal (18) and transmitting the initial CDMA signal (18) to the primary station (2) until synchronisation with the primary station (2) is obtained,
- modulating the data signal (16) with a final code word (14) in order to obtain a final CDMA signal (18) and transmitting the final CDMA signal (18) after synchronisation with the primary station (2) has been obtained,
characterized in that the initial code word is substantially orthogonal to the final code word for every possible time shift of the initial code word.

8. A method of synchronising a secondary station (4) with a primary station (2) according to Claim 7, characterized in that all symbol values of the initial code word are equal to each other.

9. A method of synchronising a secondary (4) station with a primary station (2) according to Claim 7 or 8, characterized in that the code words (14) are Walsh-Hadamard codes and that the initial code word corresponds to the first row or the first column of the Walsh-Hadamard matrix.

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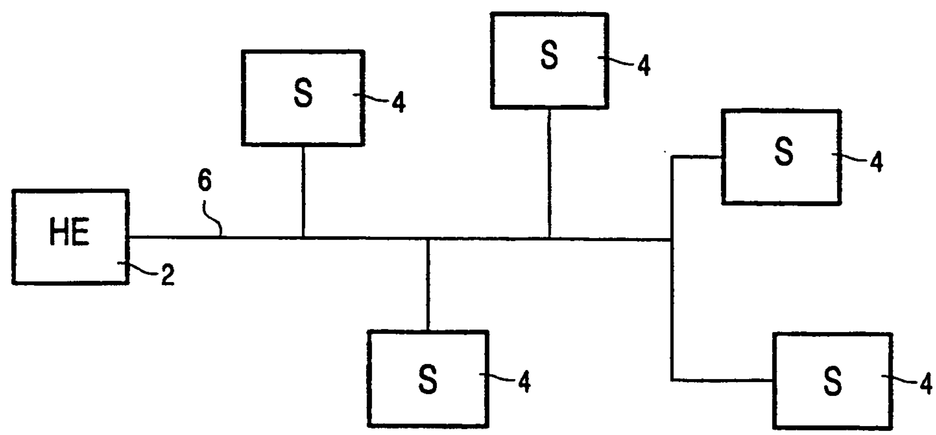

FIG. 1

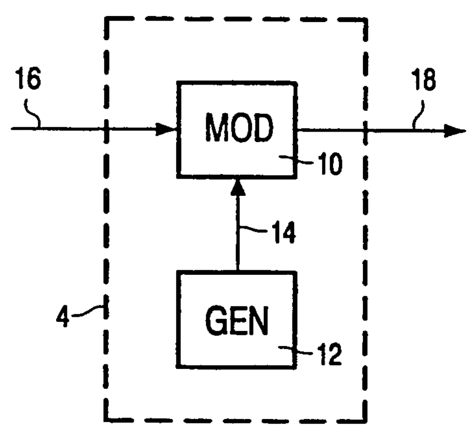

FIG. 2

JC03 Rec'd PCT/PTO 27 FEB 2001

C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	R_0
0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	R_1
0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	R_2
0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	R_3
0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	R_4
0	1	0	1	1	0	1	0	0	1	0	1	1	0	1	0	R_5
0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	R_6
0	1	1	0	1	0	0	1	0	1	1	0	1	0	0	1	R_7
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	R_8
0	1	0	1	0	1	0	1	1	0	1	0	1	0	1	0	R_9
0	0	1	1	0	0	1	1	1	1	0	0	1	1	0	0	R_{10}
0	1	1	0	0	1	1	0	1	0	0	1	1	0	0	1	R_{11}
0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	R_{12}
0	1	0	1	1	0	1	0	1	0	1	0	0	1	0	1	R_{13}
0	0	1	1	1	1	0	0	1	1	0	0	0	0	1	1	R_{14}
0	1	1	0	1	0	0	1	1	0	0	1	0	1	1	0	R_{15}

FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 00/05906

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B1/707

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, PAJ, INSPEC, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 97 31429 A (LOCKHEED CORP) 28 August 1997 (1997-08-28) abstract page 3, line 14 - line 25 page 10, line 37 -page 1, line 36; figure 1	1-9
A	US 5 499 236 A (GREENWOOD KENNETH C ET AL) 12 March 1996 (1996-03-12) cited in the application abstract; claims 1,16-18	1-9

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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27 October 2000	07/11/2000

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INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	BOTTOMLEY G E: "SIGNATURE SEQUENCE SELECTION IN A CDMA SYSTEM WITH ORTHOGONAL CODING" IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY,US,IEEE INC. NEW YORK, vol. 42, no. 1, 1 February 1993 (1993-02-01), pages 62-68, XP000363400 ISSN: 0018-9545 abstract page 62, column 1 -column 2	1-9

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 00/05906

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9731429 A	28-08-1997	US 5825835 A	20-10-1998
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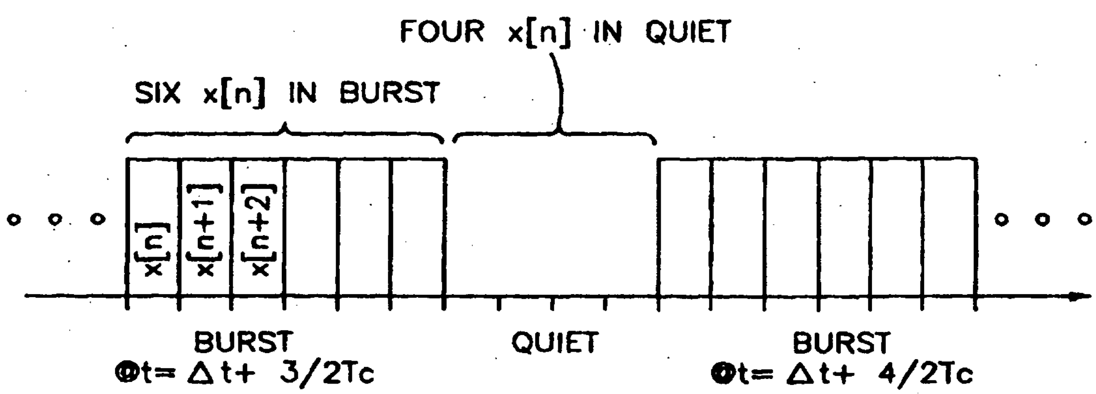
(54) Title: SYNCHRONIZATION OF TRANSMISSIONS FROM A SUBSCRIBER UNIT TO A BASE UNIT IN A RADIO CDMA COMMUNICATIONS SYSTEM



(57) Abstract

Disclosed are methods and apparatus for use in a synchronous CDMA communications system (10) that employs orthogonal pn spreading codes. The methods are intended for synchronizing transmissions from a subscriber unit (SU 14) to a radio base unit (RBU 12), and include the steps of: (a) transmitting individual ones of a plurality of bursts from the SU to the RBU, each burst being transmitted with a different pn spreading code timing alignment; (b) receiving individual ones of the plurality of bursts with the RBU and determining a power estimate of each received burst; and (c) in response to a determined power estimate of one of the bursts exceeding a threshold, sending a message from the RBU to the SU. The message indicates that the SU is to use for subsequent transmissions the pn spreading code timing alignment that was employed when transmitting the burst that exceeded the threshold. In a preferred embodiment of this invention the step of transmitting transmits an indication of the pn spreading code timing alignment used when transmitting a given one of the bursts. Each burst is transmitted with a pn spreading code timing alignment that differs by 1/2 chip from a previous pn spreading code timing alignment.

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SYNCHRONIZATION OF TRANSMISSIONS FROM A SUBSCRIBER UNIT TO A BASE UNIT IN A RADIO CDMA COMMUNICATIONS SYSTEM

CROSS-REFERENCE TO A RELATED PATENT APPLICATION:

This patent application is related to commonly assigned U.S. Patent Application Serial Number 08/ 606,378 , filed 02/23/96 , entitled "A MULTI-USER ACQUISITION PROCEDURE FOR POINT-TO-MULTIPOINT SYNCHRONOUS CDMA SYSTEMS", by S. Kingston et al. (Attorney Docket No. DUT 512).

FIELD OF THE INVENTION:

This invention pertains generally to code division, multiple access (CDMA) communication systems and, in particular, to direct-sequence (DS) multipoint-to-point synchronous CDMA communications systems.

BACKGROUND OF THE INVENTION:

In a CDMA communications system a plurality of user communication signals can be transmitted within, i.e., share, a same portion of the frequency spectrum. This is accomplished by providing a plurality of different pseudonoise (pn) binary code sequences (e.g., one for each user) that modulate a carrier, thereby "spreading" the spectrum of the resulting waveform. In a given receiver all of the user signals are received, and one is selected by applying an assigned one of the pn binary code sequences to a correlator to extract only the signal energy intended for the receiver, thereby "despreading" the received CDMA

transmission. All other (uncorrelated) user transmissions appear as noise.

One type of CDMA communication system is specified by a document referred to as EIA/TIA/IS-95. The system as specified uses a plurality of base stations that establish and maintain bidirectional direct-sequence (DS) CDMA links with a plurality of mobile stations (e.g., cellular telephones). One feature of the IS-95 system is the presence of a pilot channel that is transmitted by each base station.

The pilot channel is an unmodulated, direct-sequence spread spectrum signal that is transmitted continuously by each CDMA base station. The pilot channel allows a mobile station to acquire the timing of the Forward CDMA channel (i.e., from the base station to the mobile station), provides a phase reference for coherent demodulation, and provides a reference for signal strength comparisons between base stations for determining when to handoff. The pilot pn sequence is defined as a pair of modified maximal length PN sequences with period 2^{15} that are used to spread the Forward CDMA channel and the Reverse CDMA channel. Different base stations are identified by different pilot PN sequence offsets. A pilot pn sequence offset index is defined to be in units of 64 pn chips, relative to a zero offset pilot pn sequence. A pn chip is defined as one bit in the pn sequence. The pilot strength is defined as the ratio of received pilot energy to overall received energy.

Walsh functions are a class of 2^N time orthogonal binary functions that are used to establish orthogonality between the different pn binary code sequences used by the pilot and user channels.

In conventional practice it is known to vary the base station's receiver timing phase until synchronization with

a subscriber unit is achieved. However, this technique performs poorly due at least to the large amount of multi-user interference that is present when the receiver varies its timing offset from a correct value. This is because the multi-user interference power level will be comparable to the signal power when the user is not synchronized in a synchronous CDMA communications system. As such, the receiver has difficulty in distinguishing the correct timing phase from incorrect phases due to the strong interference.

OBJECTS OF THE INVENTION:

It is a first object of this invention to provide methods and apparatus to enable a subscriber unit to synchronize to a synchronous CDMA communications system.

It is a second object of this invention to provide methods and apparatus to enable subscriber units using orthogonal pn sequences to synchronize to a synchronous CDMA communications system, wherein a given one of the subscriber units varies its transmitter timing phase until a radio base unit signals the subscriber unit to terminate varying the timing phase, thereby selecting a current timing phase for use by the subscriber unit.

It is a further object of this invention to provide methods and apparatus to enable subscriber units using orthogonal pn sequences to synchronize to a synchronous CDMA communications system, wherein a given one of the subscriber units varies its transmitter timing phase over a large number (typically twice the processing gain) timing phases, while a radio base unit monitors the received transmissions and selects a best timing phase for use by the subscriber station.

SUMMARY OF THE INVENTION

The foregoing and other problems are overcome and the objects of the invention are realized by methods and apparatus in accordance with embodiments of this invention, wherein a subscriber unit is provided with circuitry and methods enabling synchronization with a central point, e.g., a radio base unit, of a CDMA communications system in the presence of a plurality of interfering other subscriber units.

In a first aspect this invention teaches a method for use in a synchronous CDMA communications system that employs orthogonal pn spreading codes. The method is intended for synchronizing transmissions from a subscriber unit (SU) to a radio base unit (RBU), and includes the steps of: (a) transmitting individual ones of a plurality of bursts from the SU to the RBU, each burst being transmitted with a different pn spreading code timing alignment; (b) receiving individual ones of the plurality of bursts with the RBU and determining a power estimate of each received burst; and (c) in response to a determined power estimate of one of the bursts exceeding a threshold, sending a message from the RBU to the SU. The message indicates that the SU is to use for subsequent transmissions the pn spreading code timing alignment that was employed when transmitting the burst that exceeded the threshold. In a preferred embodiment of this invention the step of transmitting transmits an indication of the pn spreading code timing alignment used when transmitting a given one of the bursts. Each burst is transmitted with a pn spreading code timing alignment that differs by 1/2 chip from a previous pn spreading code timing alignment.

The RBU executes the following steps when receiving the SU burst transmissions: summing M samples per chip to obtain a first result; despreading the first result; summing L

chips per symbol from the first result to obtain a second result; summing a plurality of symbols from the second result to obtain a power estimate of a current pn spreading code timing alignment that was transmitted by the SU; obtaining a scaled averaged power estimate that includes a power estimate from a previous pn spreading code alignment for forming the threshold; and comparing the power estimate of the current pn spreading code timing alignment to the threshold.

If the SU exhausts a predetermined range of permissible pn spreading code timing alignments without receiving a message from the RBU, the SU, performs the steps of increasing an output power of an SU transmitter, and then re-transmitting the plurality of bursts.

Each transmitted burst is preferably separated by a period of no transmission by the SU (i.e., a "quiet" period). During this time the RBU may also determine a power estimate.

Further in accordance with this invention the method executes the steps of: in response in the RBU sending the message, changing the pn spreading code timing alignment by a predetermined number of chips; transmitting individual ones of a second plurality of bursts from the SU to the RBU, each burst being transmitted with a different pn spreading code timing alignment; receiving the second plurality of bursts in RBU and storing, for each received burst, a corresponding magnitude of a pn correlation value; and after receiving a predetermined number of the second bursts, transmitting a message to the SU from the RBU. In this case the message instructs the SU to use for subsequent transmissions a pn spreading code timing alignment that corresponds to a largest stored pn correlation value.

BRIEF DESCRIPTION OF THE DRAWINGS

The above set forth and other features of the invention are made more apparent in the ensuing Detailed Description of the Invention when read in conjunction with the attached Drawings, wherein:

Fig. 1 is a simplified block diagram of a synchronous, DS-CDMA communications system in accordance with this invention, the system having a radio base unit (RBU) and a plurality of transceiver or subscriber units (SUs). The RBU transmits a side channel to the SUs, and also receives an essentially asynchronously transmitted side channel from the SUs.

Fig. 2 is a block diagram of the pn code acquisition procedure for the asynchronous side channel receiver of the RBU of Fig. 1. The detection threshold is determined using an IIR filter that removes any dependency on dynamic AGC levels.

Fig. 3A is a graph that illustrates energy versus timing offset for a desired (asynchronous) user, for multiuser interference, and for background noise.

Fig. 3B is a graph that illustrates energy versus timing offset for the desired (now synchronized) user, for the multiuser interference, and for the background noise.

Figs. 4A and 4B are a flow chart of an asynchronous reverse link side channel procedure, as executed by a SU in cooperation with the RBU.

Fig. 5 is a timing diagram that illustrates RBU timing and epoch as well as an initial timing of a received SU signal. The epoch for the SU signal is unknown.

Fig. 6 is a time domain representation of bursts and "quiet" periods.

Fig. 7 is a graph illustrating an autocorrelation function of a pn spreading sequence. A peak exists in this function at $\tau=0$.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, a synchronous CDMA communications system 10, which in presently preferred embodiments of this invention is embodied as a fixed wireless system (FWL), is considered herein to be a CDMA system wherein forward link (FL) transmissions from a radio base unit (RBU) 12 for a plurality of transceiver units, referred to herein as user or subscriber units (SUs) 14, are bit and chip aligned in time, and wherein the SUs 14 operate to receive the FL transmissions and to synchronize to one of the transmissions. Each SU 14 also transmits a signal on a reverse link (RL) to RBU 12 in order to synchronize the timing of its transmissions to the RBU, and to generally perform bidirectional communications. The synchronization aspect is of most concern to the teaching of this invention. The FWL is suitable for use in implementing a telecommunications system that conveys voice and/or data between the RBU 12 and the SUs 14.

The RBU 12 includes circuitry for generating a plurality of user signals (USER_1 to USER_n), which are not shown in Fig. 1, and an asynchronous side channel (SIDE_CHAN) signal that is continuously transmitted. Each of these signals is assigned a respective pn spreading code and is modulated therewith before being applied to a transmitter 12a having an antenna 12b. When transmitted on the FL the transmissions are modulated in phase quadrature, and the SUs 14 are assumed to include suitable phase demodulators for deriving in-phase (I) and quadrature (Q) components

therefrom. The RBU 12 is capable of transmitting a plurality of frequency channels. By example, each frequency channel includes up to 31 code channels, and has a center frequency in the range of 2 GHz to 3 GHz.

The RBU 12 also includes a receiver 12c having an output coupled to a side channel receiver 12d. The side channel receiver 12d is shown in greater detail in Fig. 2. The side channel receiver 12d receives as inputs the spread signal from the receiver 12c, a scale factor signal, and a side channel despread pn code. These latter two signals are sourced from a RBU processor or controller 12e. The scale factor signal can be fixed, or can be made adaptive as a function of a number of SUs 14 that are transmitting on the reverse side channel. The side channel receiver 12d outputs a detect/not detect signal to the RBU controller 12e for indicating a detection of a transmission from one of the SUs 14, and also output a power estimate value χ, as described below. A read/write memory (MEM) 12f is bidirectionally coupled to the RBU controller 12e for storing system parameters and other information, such as SU timing phase information and power estimate values, as will be described in further detail below.

Referring to Fig. 2, the side channel receiver 12d receives the spread signal from the receiver 12c and sums some M samples per chip. The sampled spread signal is then despread using the assigned side channel pn code, after which is performed, on soft decisions of the despread signal, a summation of L chips per symbol. The absolute value of some number (e.g., 256) symbols is then determined, which provides the power estimate χ. Summing over 256 symbols reduces the variance of this estimate and thus yields a more accurate result. The power estimate is applied to a detect/not detect comparison block and also to a block that performs a computation of an average power estimate using the expression:

$$y[n]=\alpha x[n]+(1+\alpha)y[n-1],$$

where $y[n]$ is an estimate of the unsynchronized power level, $x[n]$ is a power estimate at current pn code alignment, and $y[n-1]$ is a previous power level estimate. The term α is a parameter that determines how fast the average power level responds to the current power estimate. The calculated current value of $y[n]$ is then multiplied by a scaling factor to yield a detection threshold value for use by the comparator block in making a current detect/not detect decision based on the current power estimate χ. If the current power estimate is larger than the threshold, a detection is declared and this information is then fed back to the transmitting SU 14, as described below with respect to Figs. 4A and 4B. If the current power estimate is not larger than the threshold, a not detect state is declared instead. In the method described below the SU 14 can slip its timing by 1/2 chip and then transmit again.

Reference in this regard can be had to Fig. 6, wherein there is illustrated a time domain representation of bursts and "quiet" periods. In this example a burst of six power estimates ($x[n]$) is followed by a quiet period of four power estimates. The next burst is then transmitted by an SU 14 with a pn phase that is delayed (slipped) by 1/2 chip from the previous phase.

The acquisition procedure of this invention makes use of one of the properties of the spreading sequences. When the spread signal from the asynchronous side channel is aligned in time with the timing of the side channel receiver 12d, the energy as measured by the receiver 12d is greater in magnitude than when not aligned (see, for example, Fig. 5). This is due to the autocorrelation function of the spreading sequences, as is illustrated in Fig. 7. Therefore, the largest power estimate results when the side channel signal that is transmitted by the SU 14 is in alignment with the timing of the RBU's side channel

receiver 12d.

Referring again to Fig. 1, each SU 14 includes an antenna 14a, a receiver 14b, a correlator 14c wherein the received FL transmission is despread using, by example, the side channel despreading pn code, and a SU processor or controller 14d. The SU controller 14d is responsible for managing the operation of the SU 14. These management functions include generating a variable local oscillator (LO) signal for down-converting a received FL signal, and providing the pn binary code sequences that are assigned to the SU 14 for despreading the side channel and also the user's signal. The SU controller 14d is also responsible for executing one or more of the synchronization methods in accordance with this invention, in cooperation with the RBU controller 12e. The SU 14 also includes a spreading circuit 14e for spreading a signal, such as the side channel signal, and a transmitter 14f for transmitting the DS-CDMA signal on the RL to the RBU 12.

For the presently preferred embodiments of this invention the antennas 12b and 14a have a line-of-sight relationship, the SUs 14 are fixed in location with respect to the RBU 12, and the antennas 12b and 14a are boresighted during installation of the SU 14. However, and as will be discussed below, the teachings of this invention are not limited to only this particular presently preferred arrangement.

The ensuing description assumes a DS signal, a(t), with code symbol duration T_s, multiplied by a spreading sequence c(t), with chip duration T_c and a null-to-null bandwidth $W_c = 2/T_c$. By example, there may be $M \leq 30$ active users (SUs 14) in the CDMA communication system 10, each of which receives coded information symbols from the RBU 12, with an assigned length of $P = 32$ code. All of the pn codes are mutually orthogonal when aligned, and are assumed to be accurately

aligned during normal operation. In a presently preferred embodiment of this invention the pn codes are selected from a set of randomized Walsh-Hadamard codes. The symbol rate for each SU 14 is fixed at $1/T_s$, and the chipping rate at $1/T_c = P/T_s$. The teaching of this invention is not, however, limited to only signals having these characteristics. By example, the set of spreading codes can be selected from any set that exhibits low cross-correlation at zero relative shift.

Furthermore, the ensuing description is directed towards presently preferred embodiments of methods for synchronization of the SU's spreading code timing at the RBU 12. These embodiments differ from conventional synchronization schemes, which are applicable for single-user systems, in that allowance is made for the presence of a number of interfering users (i.e., other SUs 14) on the same channel. In general, the methods of this invention search a range of possible timing offsets by varying the transmitter timing of the SU 14, and not by varying the RBU receiver timing, as is done in conventional approaches.

The methods, in a presently preferred embodiment of this invention, specifically apply to the asynchronous side channel, the use of which is assumed to be infrequent (e.g., during provisioning, after SU power outages, etc.).

The methods of this invention provide a means by which an SU 14 can become resynchronized to the system 10 in the event that it loses knowledge of the correct timing offset at which it should transmit. This invention uses a specific, dedicated signature sequence (pn spreading code), assigned at the time of system provisioning (i.e., during the installation of the SU 14 at the user's location, boresighting of the SU antenna 14a with the RBU antenna 12b, and initial acquisition by the SU 14 of the forward and reverse channels). Since the FL is continuously

transmitting, when an SU 14 is activated one of the first operations that it performs is to acquire the FL side channel and begin processing the side channel data accordingly. Under normal operating conditions (after the SU 14 is successfully provisioned), the SU 14 stores the value of a timing offset at which it has been instructed (by the RBU 12) to transmit. The timing offset value is relative to a symbol boundary or epoch as defined by the received forward channel signal. If for some reason the SU 14 loses knowledge of this timing offset value, or has not yet obtained the value, as during initial provisioning, the SU 14 has no means of determining exactly when it should transmit. Thus, when it does begin transmission, it begins transmitting essentially asynchronously, as perceived at the RBU 12. This has the effect of introducing multi-user interference (MUI) to any other users on the RL, and in addition makes the detection of the asynchronously transmitting SU at the RBU 12 a more difficult problem, since from the perspective of the asynchronously transmitting SU's received signal, all other active users contribute MUI.

Given that asynchronous side channel usage by the SUs 14 is generally infrequent, a longer acquisition time can be tolerated on this channel. However, the sooner an asynchronously transmitting SU 14 is made synchronous, the sooner it stops contributing to, and suffering from, MUI.

The synchronization technique of this invention exploits the orthogonality of the signature (pn code) sequence set to aid in acquisition. If a given one of the SUs 14 is transmitting asynchronously, the resulting MUI makes detection of the asynchronous user more difficult, since the value of the detector output contains MUI that can be as large as the desired signal correlation (as shown in Fig. 3A).

In Fig. 3A the solid curve represents the RBU detector (correlator) output energy (see Fig. 2) when MUI is input, and the dashed curve represents the detector output energy when the input is the desired SU signal, where in both cases the RBU 12 correlates with the desired SU signature sequence. Thus the timing offset axis is with respect to the desired SU receiver. Henceforth, reference is made to the (initially) asynchronous SU or user as the "desired" SU or user.

When a number (N-1) of synchronous SUs are present, the detector input signal is actually the sum of the desired user signal plus the MUI. Clearly, when the desired SU's timing offset is greater than approximately 1/2 of the chip duration T_c, the desired SU detector, which is correlating with an offset of zero, does not yield a high signal-to-noise ratio (SNR). In this situation, the SNR is approximately equal to $(E_{bj}/P)/(N_o+I_o+\Delta I_o)$, where E_{bj} denotes the energy of the desired SU's correlation, P is the processing gain, N_o represents the thermal noise (assumed small here), I_o is the multi-user interference caused by pulse shape filtering, and the term ΔI_o represents additional MUI caused by the imperfect synchronization of the synchronous SUs. The desired SU's detection SNR is also indicated in Fig. 3A. By example, if P = 32 the detection SNR for an asynchronous SU is reduced by 10log(P) = 15 dB from the synchronous value. Further by example, if P = 128 then the corresponding SNR loss is approximately 21 dB.

In cases where the desired SU's received signal is faded, or when the ΔI_o term of the MUI is relatively large because of additional small timing offsets of the synchronous SUs 14, the reduction in detection SNR from asynchronism can be sufficient to prevent declaration of a "detection" at all, or will result in an unacceptably high bit error ratio (BER). In this case, the RBU 12 may not be able to

instruct the desired SU 14 to correct its timing. If the desired SU's receiver at the RBU 12 were to shift its timing, the absolute energy of the detector output would increase, but the detection SNR would be even lower. Thus, what is required is an alternate technique to acquire the desired SU's signal at the RBU 12.

This alternate technique, in accordance with a first embodiment of this invention, is accomplished by having the SU 14 shift the timing of the transmitted signal until it comes into synchronism, as shown in Fig. 3B. The asynchronous side channel transmissions are burst transmissions, and after each burst, the SU 14 waits for a response from the RBU 12. Contained in each burst is the timing offset value used to transmit the burst. The response from the RBU 12 includes information as to a SU timing adjustment. If after a prescribed waiting period the SU 14 receives no response from the RBU 12, the SU 14 transmits another burst at another timing phase. This process is repeated until the SU receives a response, or has tried all possible values of timing offset (e.g., 64 or 256 half-chip values. If after all values of timing offset have been tried by the SU 14, and no response has been received from the RBU 12, the SU 14 increases its transmit power by some increment, and repeats the process.

In some cases the asynchronous detection SNR is sufficient for the RBU's receiver 12d to process the signal. If the asynchronous SU's timing offset is such that an autocorrelation sidelobe lies at the correct timing phase, then it is possible that the detection SNR is adequate for processing the received signal. If this occurs the desired SU's receiver in the RBU 12 may conclude that the SU 14 is experiencing a fade, and can therefore command the SU 14 over the FL to increase its transmit power. This can result in raising the MUI level seen by the synchronous SUs 14, and could degrade their performance.

To avoid this possibility, and in accordance with a second embodiment of this invention, once the RBU 12 acquires the SU's signal and can adequately process the received burst transmissions, the RBU 12 responds with an acknowledgement message. The SU 14 then shifts its timing offset by some predetermined amount, for example by -J chips (e.g., J=16), and transmits again. The SU 14 then delays a prescribed amount of time, shifts its timing offset forward by 1/2 chip, and transmits again. This process is repeated until the SU 14 has transmitted 4J+1 bursts after the initial response from RBU 12. During transmission of these bursts the RBU 12 determines and stores in the memory 12f a correlation value obtained from the side channel receiver 12d. After the SU has transmitted all 4J+1 bursts, the RBU 12 responds with a command that instructs the SU 14 to use a timing phase that resulted in the largest detector correlation value. At this time, the RBU 12 and SU 14 then "fine tune" the SU timing to an optimum value.

Figs. 4A and 4B are a flow chart of the above-described asynchronous reverse side channel procedures, as carried out by the SU controller 14d in cooperation with the various other circuits of the SU 14.

At Block A the SU 14 acquires the forward side channel and at Block B transmits one burst on the reverse side channel using an initial phase timing. After a delay (e.g., 100 msec) control passes to Block C where the SU 14 determines if a response has been received from the RBU 12. Assuming for now that the result of this determination is No, control passes to Block D where a determination is made if the pn phase timing has been slipped by some maximum number (e.g., 64) of 1/2 chips. If No, control passes to Block E where the pn phase timing is slipped by 1/2 chip, and control then passes to Block B to transmit another burst with the slipped pn phase timing. If Yes at Block D, control passes to Block F to determine if the SU 14

transmitter power is at a maximum level. If No at Block F, the power of the SU transmitter 14f is increased by some increment (e.g., 3 dB) at Block G, and control passes to Block B to begin transmitting another sequence of bursts beginning with the initial phase timing offset. If Yes at Block F (i.e., the SU transmitter power is at maximum), then control passes to Block H where a determination is made if some predetermined number of passes through the loop have occurred. If No, control passes to Block B to begin transmitting another sequence of bursts beginning with the initial phase timing offset, and at the maximum power level. If Yes at Block H, control passes instead to Block I where a delay of M minutes is made (M may be a random value), the SU transmitter power level is reduced, with control eventually passing back to Block B.

Assuming now that the determination at Block C is Yes (a response is received from the RBU 12), control passes to Block J where the slipping of the pn phase timing is terminated. The SU 14 goes to a phase timing commanded by the RBU 12 and adjusts the timing as per the RBU command. At Block K the SU 14 begins slipping from -J to +J (e.g., J=16) phase timing positions with minimum delay between bursts. During this time the RBU 12 records the output of the correlator that is assigned to the SU 14. At Block L the SU 14 determines if a response is received from the RBU 12. If No, a determination is made at Block M if some predetermined number of passes have been made through the K, L, M loop. If No, control passes back to Block K. If Yes at Block M, control passes back to Block B to restart the synchronization procedure. If Yes at Block L (i.e., a response is received from the RBU 12), the SU 14 transmits at Block N a timing and confirmation burst on a channel assigned by the RBU in the response received at Block L. After transmitting the confirmation message control passes to Block O to wait for a further response from the RBU 12. If the response is not forthcoming a comparison is made at

Block P to determine if the N, O, P loop has been executed some predetermined number of times. If No, control passes back to Block N to retransmit the confirmation message. If Yes at Block P, control passes back to Block B to restart the synchronization procedure. If Yes at Block O, a determination is made if the RBU response indicates whether a large or small timing correction is required. If a large correction is required, the SU 14 adjusts its pn timing accordingly and then preferably transmits another timing and confirmation burst at Block N. If the response from the RBU 12 at Block O indicates that only a small correction is required, the SU 14 makes the indicated phase timing correction and thereafter enters the active communications mode at Block Q. That is, the SU 14 leaves the side channel and begins operating on an assigned communications channel.

In a further embodiment of this method the SU 14 steps through all possible timing offset values, during which the RBU does not reply, but stores in the memory 12f the detector correlation value at each timing phase for which sufficient SNR is present. As soon as the RBU 12 no longer detects the SU transmission, or after all possible correlation values are determined, the RBU 12 instructs the SU 14 to transmit at the timing offset value that yielded the largest correlation.

The probability of correct acquisition, given several different scenarios, can be determined for the system 10. For instance, the probability of correct detection can be determined for the case where there are no active synchronous users and the phase of the first burst is exactly 1/2 chip off of perfect alignment. This probability also depends on other factors such as the power of the asynchronous SU 14 and the threshold value determined in Fig. 2. In a worst case analysis, all non-aligned phases are transmitted before the correct phase.

In the worst case, for correct detection to take place there should not be a detection on any non-aligned phases, and the detection should take place only on the aligned burst. Also, the detection should take place on the first power estimate of an aligned burst, thereby allowing the receiver 12c of Fig. 1 sufficient time to track the carrier phase and resolve any I and Q ambiguity.

Power estimates can be calculated for all 64 phases (i.e., all 64 "slips"), as well as for the periods when the asynchronous SU transmitter is "quiet" (see Fig. 6). A large number of variables can exist when making the power estimates. By example, there can be differences in the number of active synchronous SUs, the power levels of the asynchronous SUs, and the initial timing offset relative to the 1/2 chip slips. Another variable is the dwell time or the time between bursts ("quiet" periods).

A mean and variance for all 64 phases and for the "quiet" periods can be computed. Since the power estimate is the sum of a large number of random variables, it can be assumed that the power estimate at a given phase has a Gaussian distribution.

With the knowledge of the mean and variance of the power estimates at all phases and during the "quiet" periods, as well as the mean of the average power estimates, a probability of correct detection can be calculated. For the following examples, it is assumed that the average power estimates have zero variance. Actually, for an α (filter coefficient) of 0.01, the variance of the average power estimate is many times smaller than the variance of the power estimates. Therefore, to assume that the average power estimate is a constant has little effect on the probabilities.

For a given non-aligned phase, the probability that there

is a false detection at a certain threshold is given by

Pr(false detection at phase i|phase i is transmitted) =
1-F(threshold-mean(i), √variance (i)), (1)

where F() is the cumulative distribution function of a zero mean Gaussian distribution with a variance of (i), the threshold is computed as in Fig. 2, and mean(i) is the mean of the power estimate at phase i. For clarity, the above probability is denoted as Pr(false on i). The cumulative distribution function, F() can also be written in terms of the error function,

$$F(x,\sigma)=\frac{1}{2}+\frac{1}{2}\cdot erf\left(\frac{x}{\sqrt{2}\cdot\sigma}\right) \quad (2)$$

The probability of false detection can be calculated from the previous probabilities. In the worst case, it is simply one minus the probability that the transmitter slips through all the non-aligned phases without a detection. Or,

Pr(worst case false detection) =
1-Pr(slip through non-aligned phases without detection).(3)

If the non-aligned phases are numbered from, by example, 2 to 63, the probability can be expressed that the SU transmitter slips through all the non-aligned phases without a detection as,

Pr(slip through non-aligned phases without detection) =
$(1-Pr(false\ on\ 2))^6 * (1-Pr(false\ on\ quiet))^4$
$*(1-Pr(false\ on\ 3))^6 * (1-Pr(false\ on\ quiet))^4 \ldots$
$*(1-Pr(false\ on\ 63))^6 * (1-Pr(false\ on\ quiet))^4$ (4)

or,

Pr(slip through non-aligned phases without detection =
$\prod_{i=\text{all non-aligned phases}} [(1-Pr(false\ on\ i))^6$
$* (1- Pr(false\ on\ quiet))^4)]$. (5)

For a given aligned phase, the probability that there is a true detection at a certain threshold is given by

Pr(true detection at phase i|phase i is transmitted)=
1-F(threshold-means(i), √variance(i)). (6)

For clarity, the above probability is denoted as Pr(true on i). The probability of a correct detection can be calculated from the above probabilities in the following manner:

Pr(a given acquisition is correct) =
Pr(correct phase is detected|no previous detection)
*Pr(no previous detection). (7)

In the worst case, the probability that there is no previous detection is given by equation (5). Also, it is assumed that the RBU 12 should detect on the first of six power estimates of an aligned phase to declare a correct detection. If it is assumed there are two aligned phases, then these would correspond to phases of -1/4 chip and +1/4 chip, which are now numbered as phase 0 and 1. The following probabilities are different for three aligned phases (i.e., -1/2, 0, 1/2 chip) but the approach is the same. For this example,

Pr(correct acquisition)=
Pr(correct detect on phase 0|no previous false detection)
*Pr(no previous false detection)
+ Pr (correct detect on phase 1|no previous detection)
*Pr(no previous detection)
= Pr (true on 0)*Pr(no false detection)
+ Pr (true on 1)*Pr(no false detection)
$*(1-Pr(true\ on\ 0))^6$
$*(1-Pr(false\ on\ quiet))^4$, (8)

where Pr(no false detection) is given by equation (5). This

is the worst case probability of correct detection where the SU transmitter slips through all non-aligned phases before transmitting at an aligned phase.

While the invention has thus been particularly shown and described above with respect to a number of embodiments thereof, it will be understood by those skilled in the art that changes in form and details may be made therein without departing from the scope and spirit of the invention. For example, it should be realized that the teaching of this invention is not limited to any of the exemplary frequencies, pn code lengths or types, transmitter powers, numbers of users, despreader and detector embodiments, and the like that were described above.

It should further be understood that the teaching of this invention is not limited for use with the RF transmitters and receivers illustrated in Fig. 1. That is, in other embodiments of this invention the CDMA forward and reverse link signals can be conveyed through, by example, coaxial cable or fiber optic cable. The CDMA signal could also be conveyed through water, using suitable acoustic transducers.

The above described embodiments should thus be viewed as being exemplary of the teaching of this invention, and should not be construed in a limiting sense upon the practice of this invention.

CLAIMS

What is claimed is:

1. In a synchronous CDMA communications system using orthogonal pn spreading codes, a method for synchronizing transmissions from a subscriber unit (SU) to a radio base unit (RBU), comprising the steps of:

(a) transmitting individual ones of a plurality of bursts from the SU to the RBU, each burst being transmitted with a different pn spreading code timing alignment;

(b) receiving individual ones of the plurality of bursts with the RBU and determining a power estimate of each received burst; and

(c) in response to a determined power estimate of one of the bursts exceeding a threshold, sending a message from the RBU to the SU, the message indicating that the SU is to use for subsequent transmissions the pn spreading code timing alignment that was employed when transmitting the one of the bursts.

2. A method as set forth in claim 1, wherein the step of transmitting includes a step of transmitting an indication of the pn spreading code timing alignment used when transmitting each of the plurality of bursts.

3. A method as set forth in claim 1 wherein the step of receiving includes the steps of:

summing M samples per chip to obtain a first result;

despreading the first result;

summing L chips per symbol from the first result to obtain a second result;

summing a plurality of symbols from the second result to obtain a power estimate of a current pn spreading code timing alignment that was transmitted by the SU;

obtaining an averaged power estimate that includes a power estimate from a previous pn spreading code alignment for forming the threshold; and

comparing the power estimate of the current pn spreading code timing alignment to the threshold.

4. A method as set forth in claim 1, wherein in response to the SU exhausting a predetermined range of permissible pn spreading code timing alignments, performing the steps of increasing an output power of an SU transmitter, and re-executing the steps (a)-(c).

5. A method as set forth in claim 1, wherein each burst is transmitted with a pn spreading code timing alignment that differs by 1/2 chip from a previous pn spreading code timing alignment.

6. A method as set forth in claim 1, wherein each transmitted burst is separated by a period of no transmission by the SU, and further comprising a step of also determining a power estimate during the period of no transmission by the SU.

7. A method as set forth in claim 1, and further comprising the steps of:

in response in the RBU sending the message, changing the pn spreading code timing alignment by a predetermined number of chips;

transmitting individual ones of a second plurality of bursts from the SU to the RBU, each burst being transmitted with a different pn spreading code timing alignment;

receiving the second plurality of bursts in RBU and storing, for each received burst, a corresponding magnitude of a pn correlation value; and

after receiving a predetermined number of the second bursts, transmitting a message to the SU, the message instructing the SU to use for subsequent transmissions a pn spreading code timing alignment that corresponds to a largest stored pn correlation value.

8. In a synchronous CDMA communications system using orthogonal pn spreading codes, a method for synchronizing transmissions from a subscriber unit (SU) to a radio base unit (RBU), comprising the steps of:

transmitting individual ones of a plurality of bursts from the SU to the RBU, each burst being transmitted with a different pn spreading code timing alignment;

receiving the plurality of bursts in the RBU and storing, for each received burst, a corresponding magnitude of a pn correlation value; and

after receiving a predetermined number of the plurality of bursts, sending a message to the SU, the message instructing the SU to use for subsequent transmissions a pn spreading code timing alignment that corresponds to a largest stored pn correlation value.

9. A method as set forth in claim 8, wherein the step of transmitting includes a step of transmitting an

indication of the pn spreading code timing alignment used when transmitting each of the plurality of bursts.

10. A method as set forth in claim 8, wherein each burst is transmitted with a pn spreading code timing alignment that differs by 1/2 chip from a previous pn spreading code timing alignment.

11. A synchronous CDMA communications system using orthogonal pn spreading codes, said synchronous CDMA communications system comprising at least one subscriber unit (SU) and at least one radio base unit (RBU), said synchronous CDMA communications system further comprising apparatus for synchronizing transmission from the SU to the RBU, said apparatus being comprised of:

means in said SU for transmitting individual ones of a plurality of bursts to the RBU, each burst being transmitted with a different pn spreading code timing alignment;

means in said RBU for receiving individual ones of the plurality of bursts and for determining a power estimate of each received burst; and

means, responsive to a determined power estimate of one of the bursts exceeding a threshold, for sending a message from the RBU to the SU, the message indicating that the SU is to use for subsequent transmissions the pn spreading code timing alignment that was employed when transmitting the one of the bursts.

12. A system as set forth in claim 11, wherein said transmitting means transmits an indication of the pn spreading code timing alignment used when transmitting each of the plurality of bursts.

13. A system as set forth in claim 11 wherein said receiving means is comprised of:

means for summing M samples per chip to obtain a first result;

means for despreading the first result;

means for summing L chips per symbol from the first result to obtain a second result;

means for summing a plurality of symbols from the second result to obtain a power estimate of a current pn spreading code timing alignment that was transmitted by the SU;

means for obtaining a scaled averaged power estimate that includes a power estimate from a previous pn spreading code alignment for forming the threshold; and

means for comparing the power estimate of the current pn spreading code timing alignment to the threshold.

14. A system as set forth in claim 11, wherein in response to the SU exhausting a predetermined range of permissible pn spreading code timing alignments, said SU further comprises means for increasing an output power of transmitter of the SU, and for re-transmitting individual ones of the plurality of bursts to the RBU.

15. A system as set forth in claim 11, wherein each burst is transmitted with a pn spreading code timing alignment that differs by 1/2 chip from a previous pn spreading code timing alignment.

16. A system as set forth in claim 11, wherein each

transmitted burst is separated by a period of no transmission by the SU.

17. A system as set forth in claim 11, and further comprising:

means in said SU, responsive to the RBU sending the message, for changing the pn spreading code timing alignment by a predetermined number of chips;

means for transmitting individual ones of a second plurality of bursts to the RBU, each burst being transmitted with a different pn spreading code timing alignment;

means in said RBU for receiving the second plurality of bursts and for storing, for each received burst, a corresponding magnitude of a pn correlation value; and

means in said RBU, responsive to receiving a predetermined number of the second bursts, for transmitting a message to the SU, the message instructing the SU to use for subsequent transmissions a pn spreading code timing alignment that corresponds to a largest stored pn correlation value.

18. A transceiver unit for use in a synchronous CDMA communications system using orthogonal pn spreading codes, said synchronous CDMA communications system further comprising at least one radio base unit (RBU) capable of communications with said transceiver unit, said transceiver unit comprising means for synchronizing a transmission from said transceiver unit to said RBU, said synchronizing means comprising means for transmitting individual ones of a plurality of bursts to the RBU, each burst being transmitted with a different pn spreading code timing alignment within a range of fractional chip timings, each

said burst including data for specifying the pn spreading code timing alignment used to transmit the burst; said transceiver unit further comprising means, responsive to a message received from said RBU, for setting the pn spreading code timing alignment to a value specified by the received message.

19. A transceiver unit as set forth in claim 18, wherein said plurality of bursts are transmitted on an asynchronous side channel.

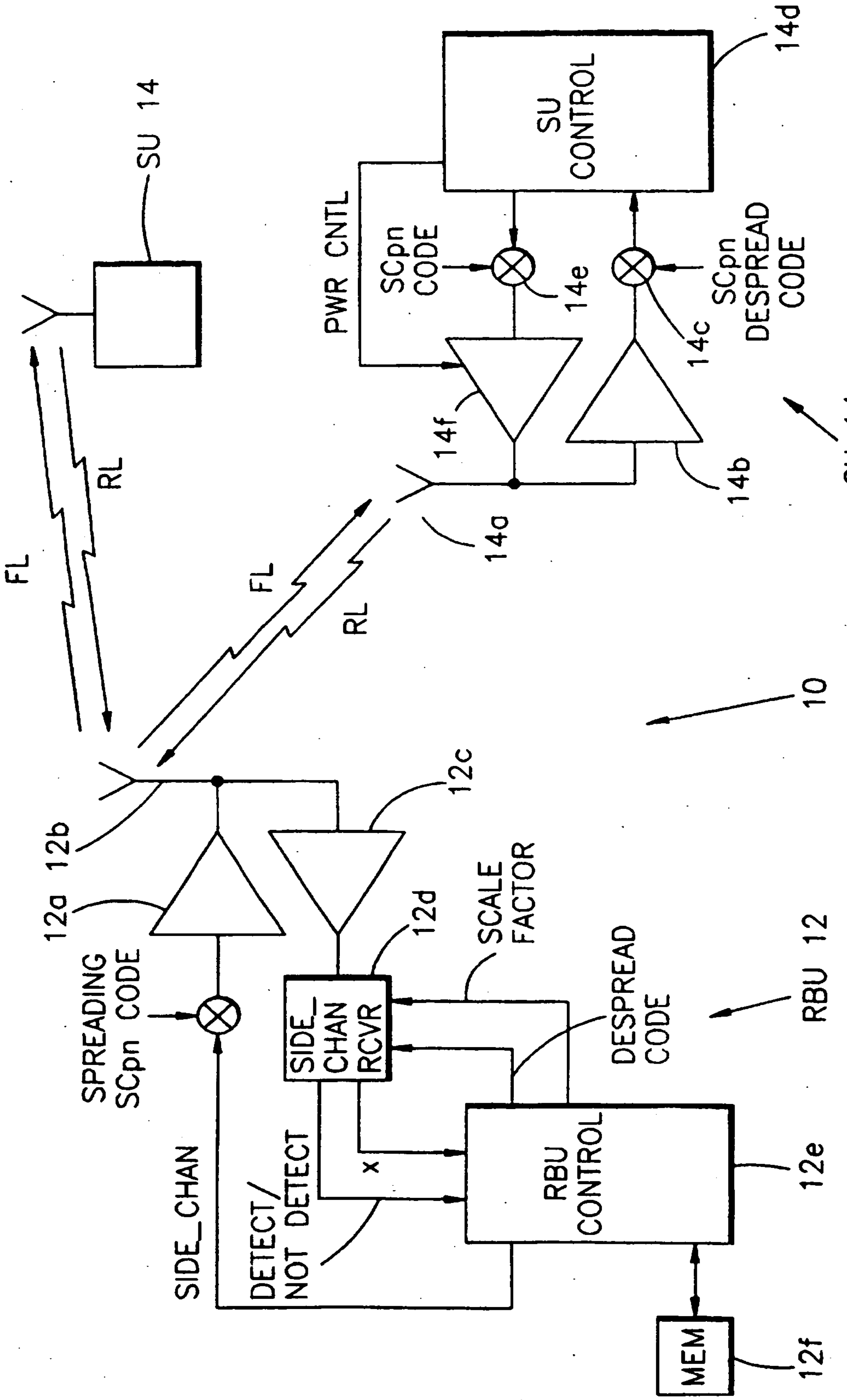
SU 14
FL
RL
FL
RL
SU CONTROL
14d
PWR CNTL
SCpn CODE
14e
SCpn DESPREAD CODE
14c
14f
14b
14a
SU 14
10
12b
12c
12a
SPREADING SCpn CODE
12d
SCALE FACTOR
SIDE_ CHAN RCVR
DESPREAD CODE
RBU 12
SIDE_CHAN
DETECT/ NOT DETECT
x
RBU CONTROL
12e
MEM
12f

FIG. 1

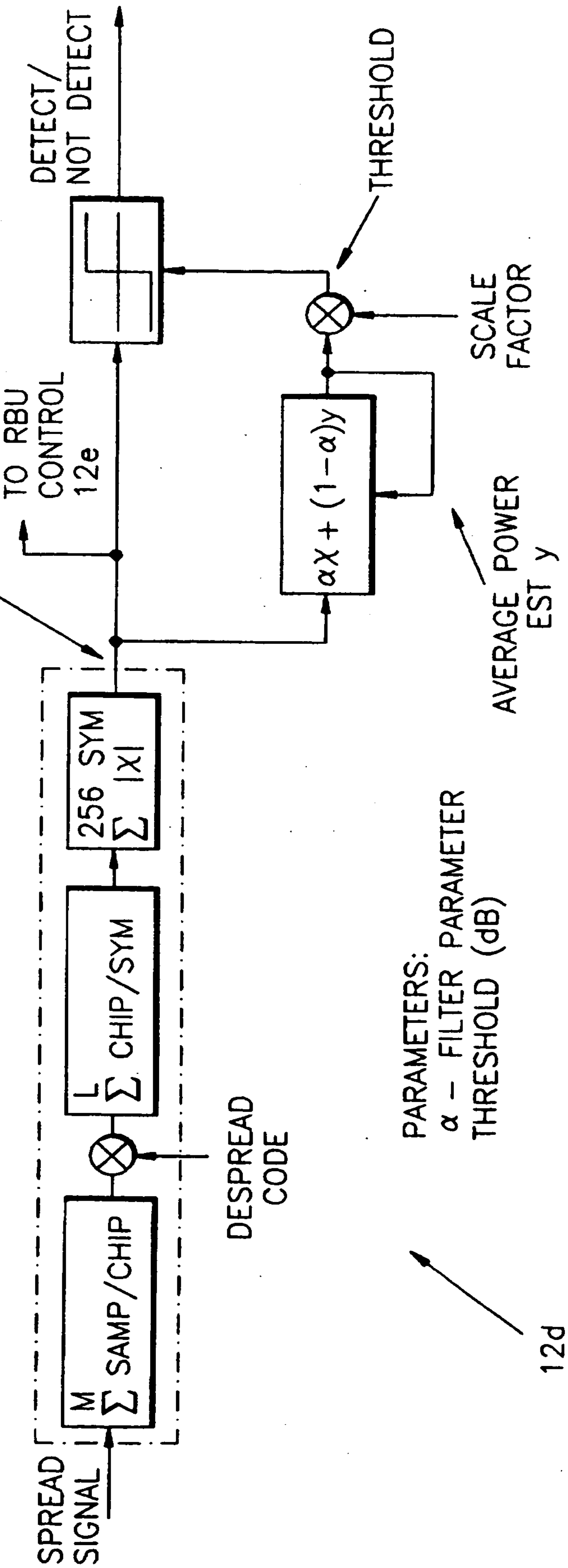
SPREAD
SIGNAL
M
Σ SAMP/CHIP
DESPREAD
CODE
L
Σ CHIP/SYM
256 SYM
Σ |X|
POWER EST
X
TO RBU
CONTROL
12e
DETECT/
NOT DETECT
THRESHOLD
SCALE
FACTOR
αX + (1−α)y
AVERAGE POWER
EST y
PARAMETERS:
α – FILTER PARAMETER
THRESHOLD (dB)
12d

FIG. 2

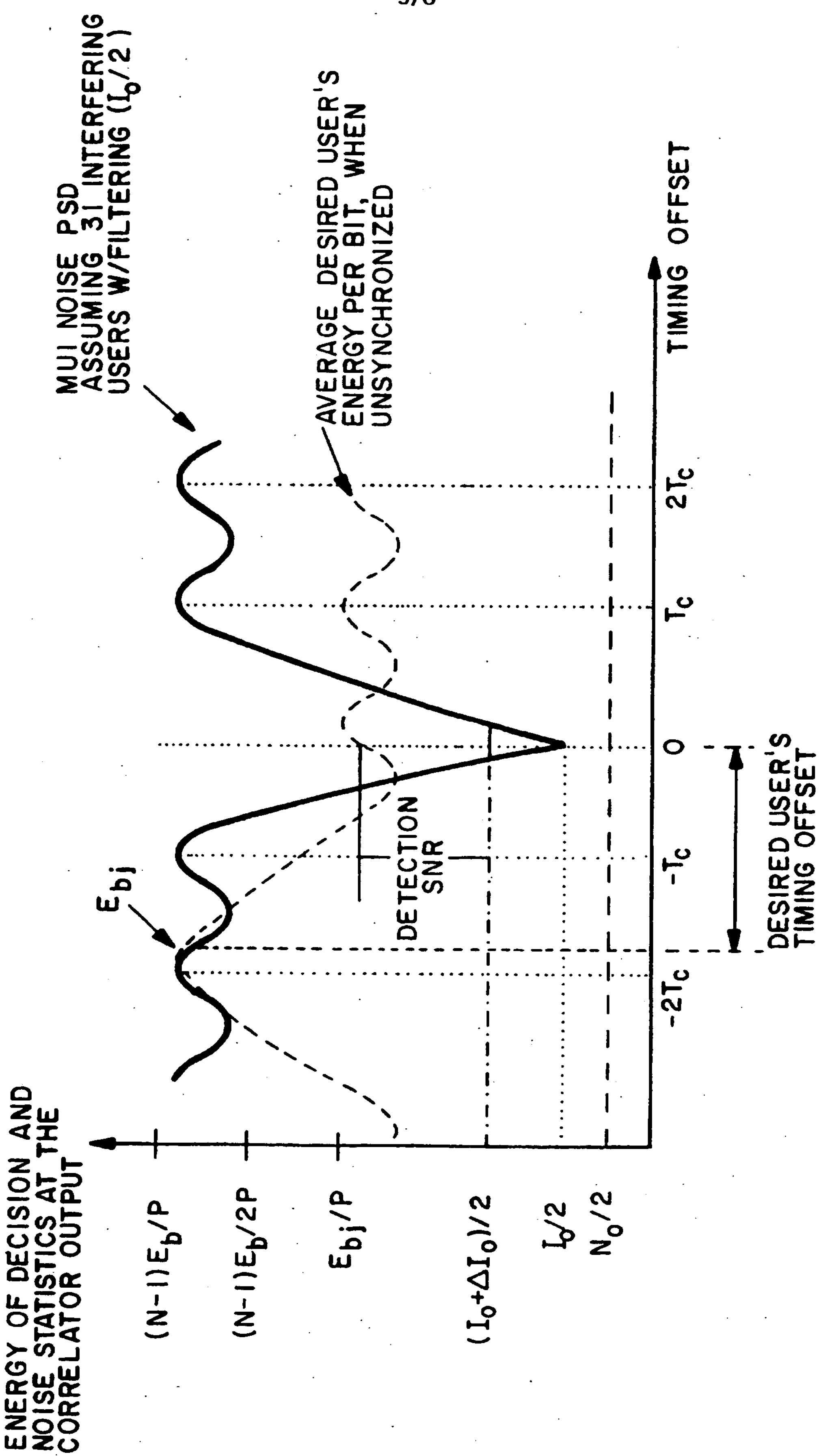
ENERGY OF DECISION AND NOISE STATISTICS AT THE CORRELATOR OUTPUT
$(N-1)E_b/P$
$(N-1)E_b/2P$
E_{bj}/P
$(I_o+\Delta I_o)/2$
$I_o/2$
$N_o/2$
MUI NOISE PSD ASSUMING 31 INTERFERING USERS W/FILTERING (I_o/2)
AVERAGE DESIRED USER'S ENERGY PER BIT, WHEN UNSYNCHRONIZED
E_{bj}
DETECTION SNR
$-2T_c$
$-T_c$
0
T_c
$2T_c$
TIMING OFFSET
DESIRED USER'S TIMING OFFSET

FIG. 3A

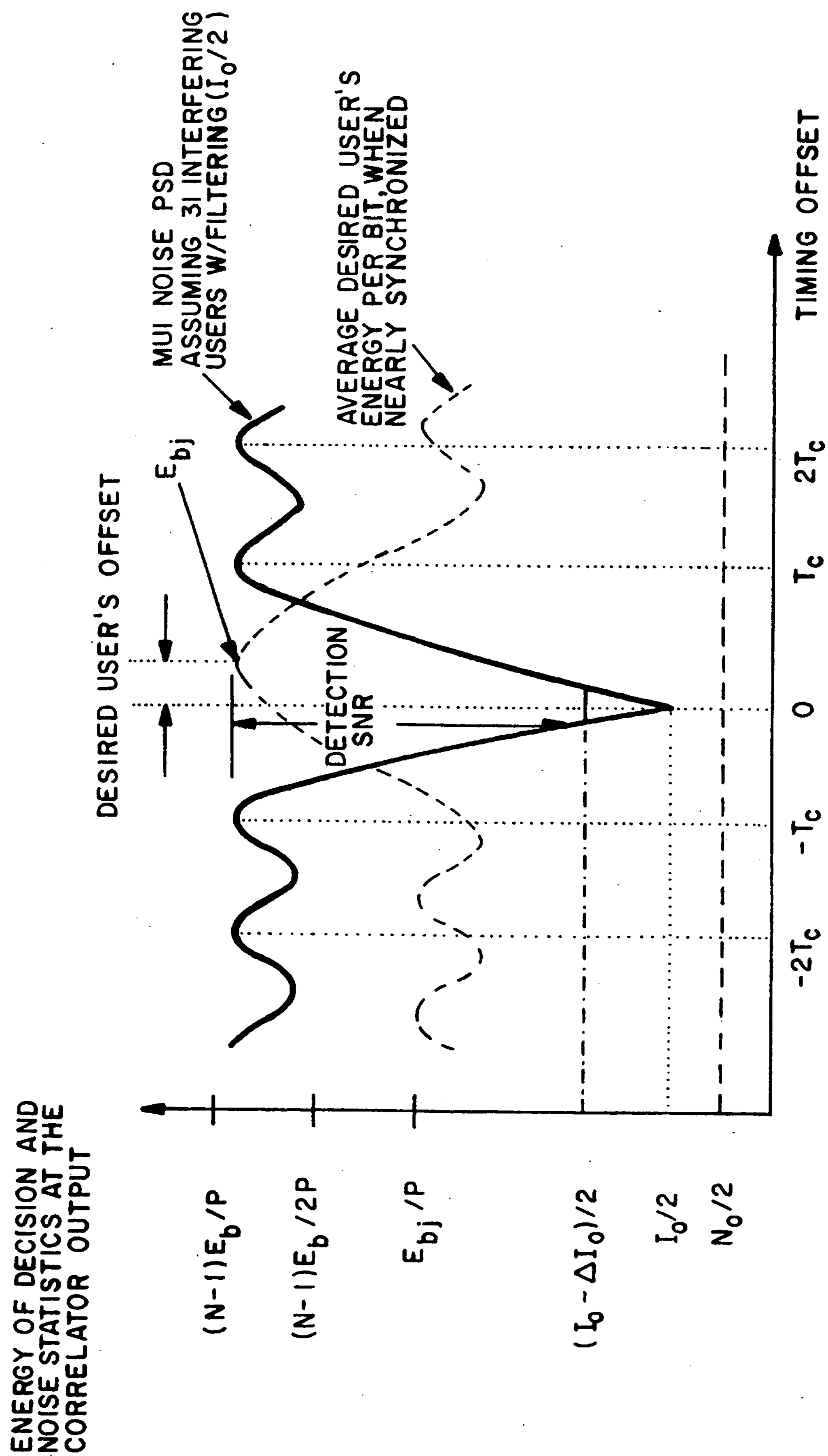
ENERGY OF DECISION AND NOISE STATISTICS AT THE CORRELATOR OUTPUT
$(N-1)E_b/P$
$(N-1)E_b/2P$
E_{bj}/P
$(I_o-\Delta I_o)/2$
$I_o/2$
$N_o/2$
DESIRED USER'S OFFSET
E_{bj}
MUI NOISE PSD ASSUMING 31 INTERFERING USERS W/FILTERING $(I_o/2)$
DETECTION SNR
AVERAGE DESIRED USER'S ENERGY PER BIT, WHEN NEARLY SYNCHRONIZED
$-2T_c$
$-T_c$
0
T_c
$2T_c$
TIMING OFFSET

FIG. 3B

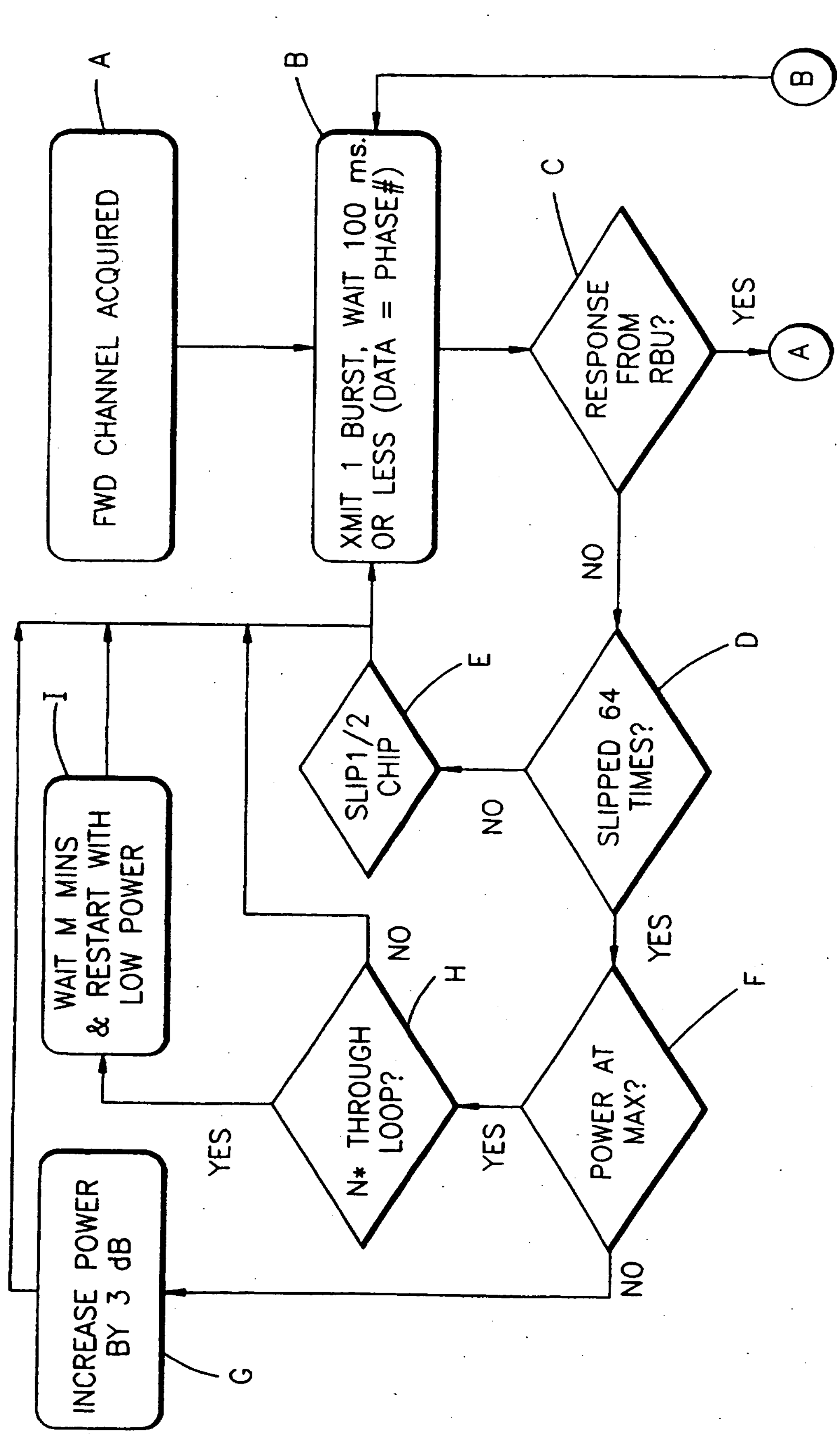
FWD CHANNEL ACQUIRED
A
XMIT 1 BURST, WAIT 100 ms. OR LESS (DATA = PHASE#)
B
RESPONSE FROM RBU?
C
YES
NO
A
TO FIG. 4B
B
FROM FIG. 4B
SLIPPED 64 TIMES?
D
NO
YES
SLIP1/2 CHIP
E
POWER AT MAX?
F
YES
NO
N* THROUGH LOOP?
H
NO
YES
WAIT M MINS & RESTART WITH LOW POWER
I
INCREASE POWER BY 3 dB
G

FIG. 4A

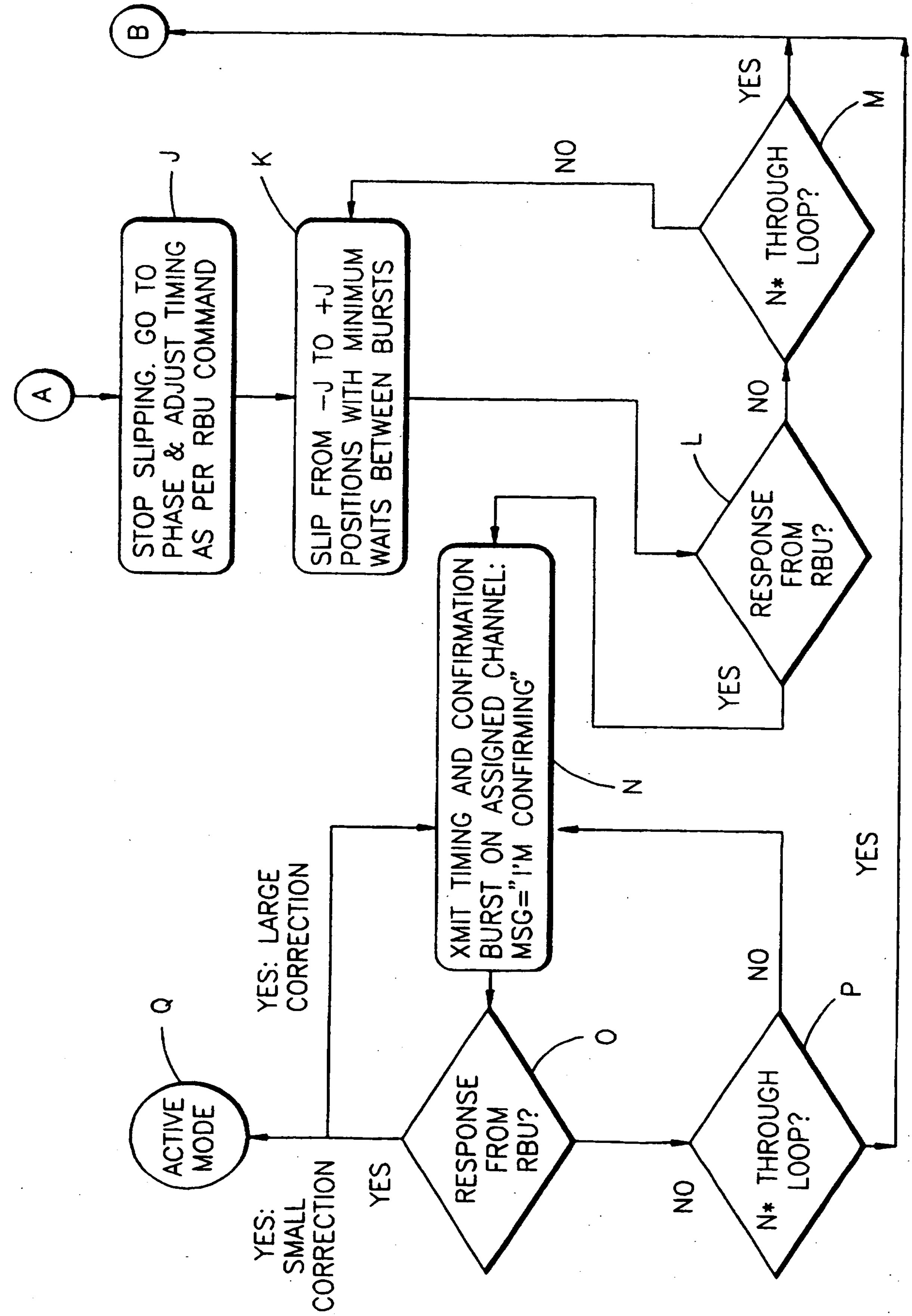
A
STOP SLIPPING. GO TO PHASE & ADJUST TIMING AS PER RBU COMMAND
J
SLIP FROM −J TO +J POSITIONS WITH MINIMUM WAITS BETWEEN BURSTS
K
RESPONSE FROM RBU?
L
NO
N* THROUGH LOOP?
M
YES
NO
B
YES
XMIT TIMING AND CONFIRMATION BURST ON ASSIGNED CHANNEL: MSG="I'M CONFIRMING"
N
RESPONSE FROM RBU?
O
YES: LARGE CORRECTION
YES
YES: SMALL CORRECTION
ACTIVE MODE
Q
NO
N* THROUGH LOOP?
P
NO
YES

FIG. 4B

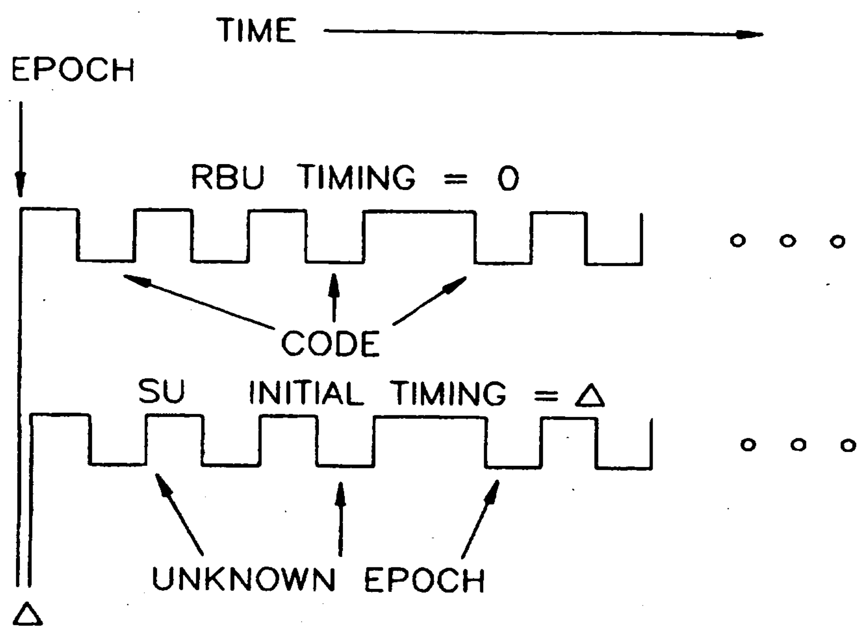
TIME
EPOCH
RBU TIMING = 0
CODE
SU INITIAL TIMING = Δ
UNKNOWN EPOCH
Δ

FIG. 5

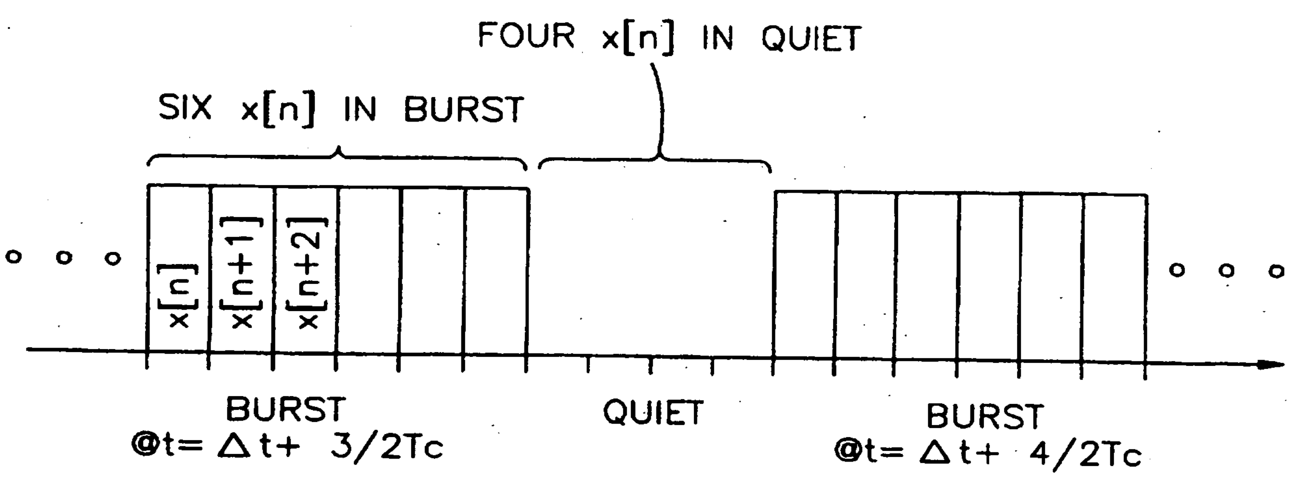
FOUR x[n] IN QUIET
SIX x[n] IN BURST
x[n]
x[n+1]
x[n+2]
BURST
@t= Δt+ 3/2Tc
QUIET
BURST
@t= Δt+ 4/2Tc

FIG. 6

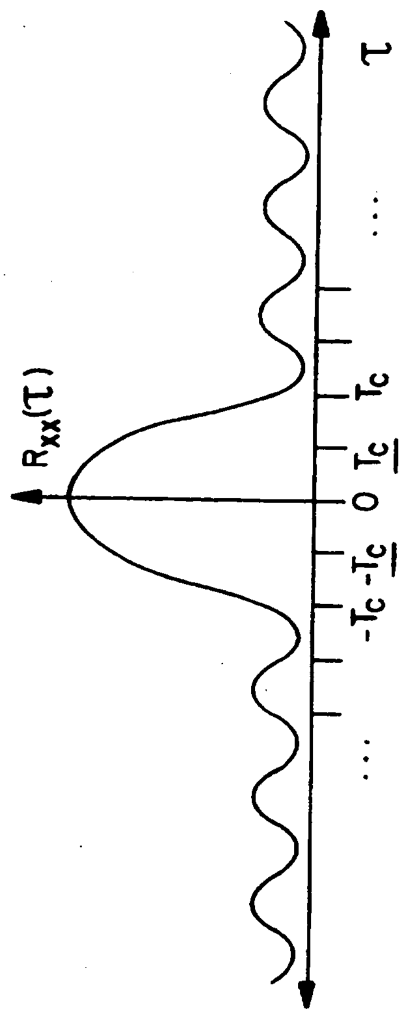

FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/02654

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B1/707 H04B7/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 295 152 A (GUDMUNDSON BJORN ET AL) 15 March 1994 see column 2, line 30 - line 50 see column 2, line 62 - column 3, line 41 see column 7, line 9 - column 8, line 55; figures 1,4,5 ---	1,2,4, 7-9,11, 12,14, 17,18
A	US 5 103 459 A (GILHOUSEN KLEIN S ET AL) 7 April 1992 see column 28, line 11 - column 29, line 4 ---	1,5,8, 10,11, 15,18
A	EP 0 654 913 A (NOKIA MOBILE PHONES LTD) 24 May 1995 see page 4, column 5, line 17 - line 35 -----	3,13

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
24 June 1997	- 4. 07. 97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+ 31-70) 340-3016	Bossen, M

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/02654

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		BR 9305475 A	27-09-94
		CA 2111001 A	28-10-93
		EP 0590134 A	06-04-94
		FI 935519 A	09-02-94
		JP 7502398 T	09-03-95
		NZ 251792 A	26-07-95
		WO 9321698 A	28-10-93
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		CN 1061312 A	20-05-92
		EP 0536334 A	14-04-93
		HU 64657 A	28-01-94
		IL 98598 A	27-02-94
		JP 6501349 T	10-02-94
		SK 387192 A	10-08-94
		WO 9200639 A	09-01-92
		US 5511073 A	23-04-96
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		US 5629955 A	13-05-97
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		CN 1116382 A	07-02-96
		JP 7202753 A	04-08-95

XP 000363400

8105 IEEE Transactions on Vehicular Technology
42(1993)February, No.1, New York, US

FEBRUARY 1993

H04J 13/00

P.62-68

Signature Sequence Selection in a CDMA System with Orthogonal Coding

H04B 1/66C1

Gregory E. Bottomley, *Member, IEEE*

H04B 7/26S

H04J 11/00

Abstract—**In code-division multiple-access (CDMA) systems, recent attention has focused on the use of orthogonal coding to provide spreading. Each signal is coded with the same orthogonal or biorthogonal code, followed by a modulo-2 addition of a unique signature sequence. The set of signature sequences used determines how much signals interfere with each other at a receiver, thus determining the performance of the system. This paper presents an analysis to determine the properties of an optimal set of signature sequences for such a system. Using a Kerdock code, a set of signature sequences is presented which optimizes performance in a direct sequence CDMA system with a) synchronous transmission, b) no multipath time dispersion, and c) orthogonal or biorthogonal Walsh–Hadamard (WH) coding as a means of spreading the information signal. For a length N binary code (N an even power of two), the set contains $N/2$ signature sequences. Approaches are discussed for the cases when N is an odd power of two and when more sequences are needed.**

I. Introduction

THERE is currently strong interest in the use of spread-spectrum multiple-access (SSMA) or code-division multiple-access (CDMA) systems for a variety of wireless communications systems, such as personal communications networks (PCN's) and cellular mobile radio [16], [17]. In a typical spread-spectrum system, a single information bit is "spread" by transmitting it as an N-bit signature sequence (or its complement) [12]. Recently, interest has focused on the use of orthogonal coding as a means of spreading the information signal [5], [18], [11]. With block orthogonal coding, $\log_2 N$ information bits are encoded into an N-bit code word. If biorthogonal coding is used, an additional information bit is sent by using the code work or its complement. An N-bit signature sequence, unique for each signal, is then modulo-2 added to the code word before transmission. Thus the orthogonal coding provides the spreading of the information signal, not the signature sequence.

From a coding point of view, each signal is assigned a code set or coset, which is formed by modulo-2 adding the signature sequence to each of N (orthogonal) or $2N$ (biorthogonal) code words [5]. Thus the system employs a supercode consisting of cosets of an orthogonal or biorthogonal code.

So far, analyses of orthogonally coded systems have assumed *random* signature sequences [5], [11]. To determine optimal performance, there is a need to identify an optimum set of signature sequences to be used in an orthogonally coded CDMA system. Such a set would depend on the particular orthogonal code used. An orthogonal code receiving recent interest is the Walsh–Hadamard (WH) code [18] (the third Hadamard code, C_n, in [10]), in which the code words are the rows of a Sylvester-type Hadamard matrix.

The purpose of this paper is to determine an optimal set of signature sequences to be used in a CDMA system where orthogonal or biorthogonal WH coding is used to spread the signal. The set is optimal in the sense that it minimizes the interference resulting from the presence of multiple signals. As a result, the probability of a decoding error is minimized, optimizing performance. While this problem has been extensively studied for traditional spread-spectrum systems [15], these results do not easily extend to the case where orthogonal coding is employed.

It is assumed that the system is synchronous, and that multipath time dispersion is not present. In other words, code words from different signals are time aligned, and no echoes of these signals are present. These assumptions were used by Rowe [14] to derive bounds on correlations for a CDMA system with orthogonal coding. They were also used by Helgert and Pickholz [6] when developing another scheme for using coding to spread the signal in a spread-spectrum system.

The paper is organized as follows. First, for the general case of asynchronous signals in the presence of multipath time dispersion, a decoder analysis is performed to determine desired correlation properties. The analysis uses the approach of Sarwate and Pursley [15]. Next, a special case is considered which assumes synchronous signals, no multipath time dispersion, and WH orthogonal or biorthogonal coding. A set of $N/2$ signature sequences of length N (N an even power of two) is obtained, with the desired correlation properties, by permuting code set representatives in a Kerdock code. It is shown that this set of sequences meets the Welch bound derived by Rowe [14]. Finally, approaches are suggested for when the length of signature sequences is an odd power of two or more than $N/2$ sequences are needed.

II. Decoder Analysis

Sarwate and Pursley analyzed a traditional CDMA decoder to show which correlation properties maximize performance [15]. Presented below is the same analysis extended to the case of biorthogonal coding. The results are then examined for the special case of a synchronous system without echoes.

Consider a binary information signal which is biorthogonally coded. For convenience, let the binary signal be represented as either $+1$ (Boolean 0) or -1 (Boolean 1). As

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IEEE Log Number 9205140.

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a result, modulo-2 addition with Boolean quantities becomes multiplication [12]. The sequence of biorthogonal code words transmitted is given by

$$\{b_i cw_{p_i}\} = \cdots, b_{-1}cw_{p_{-1}}, b_0 cw_{p_0}, b_1 cw_{p_1}, \cdots b_n cw_{p_n} \cdots \tag{2-1}$$

where cw_{p_i} is one of N N-bit orthogonal code words, and b_i is the biorthogonal information bit (± 1). The subscript p_i indicates which of the N code words is sent, and i is a code period time index. Specifically, cw_{p_i} is an N-bit sequence $cw_{p_i}(k)$ $(k = 0, N-1)$, and

$$b_i cw_{p_i}(k) = \{b_i cw_{p_i}(0), b_i cw_{p_i}(1), \cdots b_i cw_{p_i}(N-1)\} \tag{2-2}$$

Before each biorthogonal code word is sent, it is multiplied (equivalent to modulo-2 addition in Boolean form) by an N-bit signature sequence, denoted y. The "scrambled" signal sent is then given by

$$\begin{aligned}\hat{y} = \{y_i\} = \cdots, b_{-1}cw_{p_{-1}}y, b_0 cw_{p_0}y,\\ \cdot\, b_1 cw_{p_1}y, \cdots b_n cw_{p_n}y \cdots\end{aligned} \tag{2-3}$$

Specifically, $(b_n cw_{p_n}y)(k) = \{b_n cw_{p_n}(0)y(0), \cdots b_n cw_{p_n}(N-1)y(N-1)\}$. Thus the coding (not the signature sequence) provides the spreading.

At first, consider the receiver which receives only $\hat{y}$, and is synchronized to the $\hat{y}$ signal. At time period n, it receives y_n, which it correlates with all N possible scrambled code words. This is done by forming detection statistics z_j $(j = 0, \cdots N-1)$, given by

$$\begin{aligned}z_j &= \langle y_i, cw_j y\rangle = \langle b_n cw_{p_n}y, cw_j y\rangle\\ &= b_n\langle cw_{p_n}, cw_j\rangle = b_n\theta_{p_n,j}(0)\end{aligned} \tag{2-4}$$

where $\theta_{p_n,j}(0)$ is the periodic (even) correlation at zero lag between code words cw_{p_n} and cw_j. For length N orthogonal code words, $\theta_{p_n,j}(0)$ equals N if $p_n = j$, and 0 otherwise. Thus the decision as to which code word was sent (J) is given by the index of the z_j with the largest magnitude. The decision as to which b_i was sent is determined from the sign of z_J.

Now consider the presence of a second signal, $\hat{x}$. Suppose this signal is generated in a similar fashion:

$$\begin{aligned}\hat{x} = \{x_i\} = \cdots, b'_{-1}cw_{q_{-1}}x, b'_0 cw_{q_0}x,\\ \cdot\, b'_1 cw_{q_1}x, \cdots b'_n cw_{q_n}x \cdots.\end{aligned} \tag{2-5}$$

Also assume it has been shifted in time, relative to $\hat{y}$, by L code bit (i.e., "chip") periods. Thus the received signal is now $\hat{y} + T^{-L}\hat{x}$, shown graphically in Fig. 1, where T^{-L} is an operator indicating a time delay of L chip periods. This scenario models several cases:

1) interference between CDMA signals, where $\hat{x}$ is another signal;
2) interference between a signal and an echo of the signal, found in a multipath environment, where $\hat{x}$ is a delayed version of $\hat{y}$.

```
          |_________Yn_________|
          |<- L ->|
|______Xn-1_______|_________Xn_________|
```

Fig. 1. Signal y and a time shifted version of signal x.

Again, consider a receiver for the $\hat{y}$ signal, synchronized to the $\hat{y}$ signal. The received signal, during code period n of the $\hat{y}$ signal, is given by

$$r(k) = \begin{cases} y_n(k) + x_{n-1}(k+N-L), & k = 0 \cdots L-1\\ y_n(k) + x_n(k-L), & k = L \cdots N-1\end{cases} \tag{2-6}$$

where k denotes chip position within a code sequence. The receiver again correlates the received signal with the N scrambled code words for signal $\hat{y}$. During code period n, this gives:

$$\begin{aligned}z_j &= \langle r, cw_j y\rangle\\ &= \langle b_n cw_{p_n}, cw_j\rangle\\ &\quad + \sum_{k=0}^{L-1} b'_{n-1}cw_{q_{n-1}}(k+N-L)\\ &\quad \cdot x(k+N-L)cw_j(k)y(k)\\ &\quad + \sum_{k=L}^{N-1} b'_n cw_{q_n}(k-L)x(k-L)cw_j(k)y(k)\end{aligned} \tag{2-7}$$

which is similar to (2-4), with two additional "interference" terms. This expression is similar to results given by Enge and Sarwate [5], who also modeled the effects of the chip waveform and environmental noise.

To compare this result with the traditional CDMA system result, (2-7) can be expressed as

$$\begin{aligned}z_j &= b_n\theta_{p_n,j}(0) + b'_{n-1}\sum_{k=0}^{L-1} cw_{q_{n-1}}(k+N-L)\\ &\quad \cdot cw_j(k)x(k+N-L)y(k)\\ &\quad + b'_n\sum_{k=L}^{N-1} cw_{q_n}(k-L)cw_j(k)x(k-L)y(k).\end{aligned} \tag{2-8}$$

The comparable expression for the traditional CDMA system is given by [15]:

$$\begin{aligned}z &= b_n\theta_y(0) + b'_{n-1}\sum_{k=0}^{L-1} x(k+N-L)y(k)\\ &\quad + b'_n\sum_{k=L}^{N-1} x(k-L)y(k).\end{aligned} \tag{2-9}$$

Observe that if orthogonal coding is not used, i.e., cw_j is the all $+1$ sequence for all j, then (2-8) simplifies to (2-9). The two summations in (2-9) can be expressed in terms of the aperiodic cross correlation function $C_{x,y}$. However, the two summations in (2-8) are now weighted aperiodic cross correlation functions, where the weighting depends on three different code words: $cw_{q_{n-1}}$, cw_{q_n}, and cw_j. Each can take on one of N possible values.

A. Correlation Properties for the General Case

To determine specifically what correlation properties are desired in the most general case, (2-7) is first rewritten in terms of scrambled code words:

$$z_j = \langle r, cw_j y\rangle = b_n\theta_{p_n,j}(0) + b'_{n-1}\sum_{k=0}^{L-1} w_{q_{n-1}}(k+N-L)v_j(k) + b'_n\sum_{k=L}^{N-1} w_{q_n}(k-L)v_j(k) \tag{2-10}$$

where

$$v_j(k) = cw_j(k)y(k) \tag{2-11}$$

$$w_{q_n}(k) = cw_{q_n}(k)x(k) \tag{2-12}$$

$$w_{q_{n-1}} = cw_{q_{n-1}}(k)x(k) \tag{2-13}$$

and p_n is the index of the vector from one coset transmitted during time period n, q_n is the index of the vector from another (or the same) coset transmitted during time period n, and L is the delay that the vector w_{q_n} experiences relative to v_{p_n}.

Equation (2-10) models the general case of a signal v (using signature sequence y) intended for the receiver in the presence of a time shifted version (L chips) of a second signal w (using signature sequence x). This can be seen in Fig. 1 by replacing y_n with v_{p_n} and x_n with w_{q_n}. This models a) a single signal with an echo of itself ($w = v$, and $L \neq 0$), 2) two signals with no time dispersion ($w \neq v, L = 0$), and 3) a signal with an echo of another signal ($w \neq v, L \neq 0$). These three cases combined (w and v equal or not, all values of L) gives the general case of multiple asynchronous signals with time dispersion. Equation (2-10) can be written in terms of the aperiodic correlation functions [15], giving:

$$z_j = b_n\theta_{v_{p_n},v_j}(0) + b'_{n-1}C_{w_{q_{n-1}},v_j}(L-N) + b'_n C_{w_{q_n},v_j}(L). \tag{2-14}$$

Minimizing the interference terms in (2-14) gives rise to the following signature sequence design criteria for forming a set of U signature sequences:

1) optimize the aperiodic cross correlation functions $C_{x_p,x_j}(l)$, ($l = -N+1$ to $N-1$, $l \neq 0$, and $p \neq j$), between vectors within the **same coset** (there are $N(N-1)/2$ of these functions per coset, one for every combination of p and j);
2) optimize the aperiodic auto correlation functions $C_{x_p,x_p}(l)$, ($l = -N+1$ to $N-1$, $l \neq 0$), for each vector in the **same coset** (there are N of these functions per coset, one for each value of p);
3) optimize the aperiodic cross correlation functions $C_{w_q,v_j}(l)$, ($l = -N+1$ to $N-1$) between vectors of **different cosets** (there are N^2 of these functions per pair of cosets, and there are $U(U-1)/2$ different pairs).

Criteria 1) and 2) cover the interference between a signal and an echo of itself. Criterion 3) covers the interference between a signal and another (possibly delayed) signal.

Thus by selection of U different signature sequences, the goal is to optimize $UN(N-1)/2 + UN + N^2U(U-1)/2 = U(N+1)/2 + N^2U(U-1)/2$ different aperiodic correlation functions. Compare this to the traditional CDMA signature sequence selection process, where U different signature sequences are selected so as to optimize U auto correlation functions and $U(U-1)/2$ cross correlation functions, giving a total of $U(U+1)/2$ different aperiodic correlation functions ($N = 1$ in the general equation).

B. Correlation Properties for a Specific Case

Equation (2-8) can be simplified when considering the special case of a synchronous system with no multipath echoes ($L = 0$). Equation (2-8) becomes:

$$z_j = b_n\theta_{p_n,j}(0) + b'_n\sum_{k=0}^{N-1} cw_{q_n}(k)cw_j(k)x(k)y(k) \tag{2-15}$$

where y, cw_j, and b_n are the desired signal's signature sequence, transmitted orthogonal code word and transmitted biorthogonal bit, respectively. The terms x, cw_{q_n}, and b'_n are the interfering signal's signature sequence, transmitted code word and transmitted biorthogonal bit, respectively.

Furthermore, consider the case where the orthogonal code used is the WH code. The WH code has the property [2]:

$$cw_i(k)cw_j(k) = cw_{i\oplus j}(k) \tag{2-16}$$

where $i \oplus j$ denotes the bit by bit modulo-2 addition of the indices i and j. Using this property, (2-15) becomes

$$z_j = b_n\theta_{p_n,j}(0) + b'_n\sum_{k=0}^{N-1} cw_{q_n\oplus j}(k)x(k)y(k) \tag{2-17}$$

which can be expressed as

$$z_j = b_n\theta_{p_n,j}(0) + b'_n\langle cw_{q_n\oplus j}(k), x(k)y(k)\rangle. \tag{2-18}$$

Thus to minimize the interference term in (2-18), the "product" sequence $x(k)y(k)$ (i.e., the product of two signature sequences) should have low correlation with all possible code words (since $q_n \oplus j$ can take on values $0 \cdots N-1$).

To achieve the Welch bound for orthogonal cosets [14], the magnitude of this low correlation should be the same, regardless of the code words being sent. Thus the product of two signature sequences should have a constant magnitude correlation with all possible WH code words. Correlation of the product sequence with all possible code words, normalized by $1/N$, gives rise to the WH transform. Thus to minimize interference, the WH transform of the product of any two signature sequences should have a constant magnitude.

Sequences with constant magnitude WH transforms have already been identified and studied. Such sequences are a type of bent sequence of length $N = 2^n$ (n even) [1], [13], [19], not to be confused with another type of bent sequence of length $4^n - 1$ [8], [9] (recommended as signature sequences

in traditional CDMA). Thus the design criterion for forming a set of signature sequences under the assumptions given is

design criterion: the product of any two signature sequences (modulo-2 sum in Boolean) should be a bent sequence (i.e., have a constant magnitude WH transform).

Using this design criterion, interference is minimized in a direct-sequence CDMA system with synchronous transmission, no multipath time dispersion, and WH coding. Each signal is assigned a coset of a WH code, as determined by the signal's signature sequence. The WH transform of the product of any two signature sequences should have constant magnitude.

In the next section, a set of signature sequences with this property is presented. It is shown that code set representatives within a Kerdock code can be permuted to form the desired set of signature sequences.

III. Signature Sequence Construction

In this section, an optimal set of signature sequences is determined assuming a direct-sequence CDMA system that 1) employs synchronous transmission, 2) suffers no multipath time dispersion, and 3) uses orthogonal or biorthogonal WH coding as a means of spreading the information signal. Thus the set must satisfy the design criterion derived in Section II-B, that the product of any two signature sequences is a bent sequence.

There are two types of bent sequences: linearly-based bent sequences and bent-based bent sequences [1]. One approach to deriving a set of signature sequences is to use linearly based bent sequences. A linearly based bent sequence of length N can be formed by concatenating any permutation of the rows (or their complements) of a $\sqrt{N} \times \sqrt{N}$ Sylvester-type Hadamard matrix [1]. For example, for $N = 16\left(\sqrt{N} = 4\right)$, the four 4-bit WH code words are

$$wh_0 = [+1+1+1+1], wh_1 = [+1-1+1-1],$$
$$wh_2 = [+1+1-1-1], wh_3 = [+1-1-1+1]. \tag{3-1}$$

One 16-bit linearly based bent sequence is given by

$$s = [wh_0 wh_1 wh_2 wh_3] = [+1+1+1+1+1-1+1-1 +1+1-1-1+1-1-1+1]. \tag{3-2}$$

From the property of WH code words given in (2-16), the product of any two linearly based bent sequences gives a concatenation of WH code words. Unfortunately, the product is not guaranteed to use each WH code word once, and only once. Thus the product is not guaranteed to be a bent sequence.

However, by carefully choosing which permutations of code words are used, one can guarantee that the products are also permutations of code words. Such an approach generates $\sqrt{N}$ signature sequences: $\sqrt{N}-1$ linearly based bent sequences and the all zero sequence. The approach is similar to the one used by Cooper and Nettleton [4] to generate frequency hopping sequences, and it is based on the property given in (2-16). For $N = 16$, the following set of signature sequences can be formed:

$$s_0 = [wh_0 wh_0 wh_0 wh_0] \tag{3-3}$$

$$s_1 = [wh_0 wh_1 wh_2 wh_3] \tag{3-4}$$

$$s_2 = [wh_0 wh_2 wh_3 wh_1] \tag{3-5}$$

$$s_3 = [wh_0 wh_3 wh_1 wh_2] \tag{3-6}$$

where the wh_i are the 4-bit Walsh code words given in (3-1). One can verify that the product of any two signature sequences is a linearly based bent sequence. To obtain more signature sequences, bent-based bent sequences must also be employed.

From a coding point of view, signals are assigned cosets of the WH code set, which is a first-order Reed-Muller (RM) code [10]. A signature sequence set is formed by taking one code set representative from each coset. Thus the design goal is that the product of elements from different cosets must be a bent sequence. Kerdock [7] derived a code that is the union of a first-order RM code and $N/2 - 1$ cosets and has the property that the product of elements from different cosets gives a bent function [10]. Because the first-order RM code used in the Kerdock code is not a WH code, the bent function does not give rise to the type of bent sequence defined in [19]. However, by permuting each code set representative, it is possible to obtain a set of signature sequences with the bent product sequence property.

First, an arbitrary code set representative is taken from each code set in the Kerdock code, giving $N/2$ sequences. The all zero sequences can be taken from the first-order RM code set. A procedure for this is given in [10], which generates the left half ($N/2$-b) and the right half ($N/2$-b) of each code set representative separately.

Second, each $N/2$-b half of a Kerdock code set representative is permuted to obtain the left and right halves of a signature sequence. Since any permutation of the all zero sequence gives the all zero sequence, only the $N/2$-1 nonzero sequences need to be permuted. Permutation relationships between forms of first-order RM codes were first discovered by Zierler [20], with newer, simpler relationships being given more recently [3]. The permutation used here is similar to the one in [3], which uses the contents of a shift register to indicate the permutation. The permutation in [3] uses the contents of a simple shift register generator (SSRG in [12]), whereas the permutation here uses the contents of a modular shift register generator (MSRG in [12]). The permutation is based on the primitive element α in the Galois field $GF(N/2)$ used to form each half of the Kerdock code set representatives.

The permutation is defined by forming the Galois field elements in the order $0, 1, \alpha, \alpha^2, \cdots \alpha^{N/2-2}$ (which can be generated using an MSRG). These correspond to the positions 0 through $N/2$-1 in each half of the Kerdock code set representative. The corresponding position in the signature sequence is obtained by expressing each element as a k-tuple, where $k = \log_2(N/2)$. The k-tuple has the form $b_0 + b_1\alpha + \cdots + b_{k-1}\alpha^{k-1}$. By interpreting the coefficients

b_0 through b_{k-1} as coefficients of powers of 2 (i.e., $b_0 + 2b_1 + 4b_2 \cdots + 2^{k-1}b_{k-1}$), an integer in the range [0, $N/2-1$] results, giving the corresponding position in each half of the signature sequence.

Using the example in [10] for $N = 16$, the 8 Kerdock code set representatives are given in Table I. In [10], the primitive element α in $GF(8)$ used to form the Kerdock code is defined by the primitive polynomial $p(X) = X^3 + X + 1$, which gives 3-tuple representations of the elements in $GF(8)$ given in Table II [10]. Using the approach described above, the permutation mapping for each half of the sequence is also given in Table II. Applying the permutations to each Kerdock code set representative in Table I gives the set of signature sequences in Table III. Of the eight signature sequences, one is the all zero sequence (sequence 0), three are linearly based bent sequences (sequences 1, 3, and 7), and four are bent-based sequences (sequences 2, 4, 5, and 6).

IV. Other Sets and Welch's Bound

The construction method presented generates one set of signature sequences. Other sets can be generated by modulo-2 adding an arbitrary "base" N-b sequence to all the signature sequences in the set, which still preserves the property of bent product sequences. It may be possible to choose a base sequence (e.g., an extended PN sequence) so that correlation properties for the general case of asynchronous transmission with multipath time dispersion are good.

Now consider the orthogonal coding case, in which the CDMA system uses signature sequences to generate $N/2$ cosets of an orthogonal code, each coset containing N orthogonal elements. Under the assumptions of a synchronous system without time dispersion, Rowe [14] extended Welch's bound to the case of w elements divided into cosets of A elements each (i.e., w/A cosets). His result is given by

$$\frac{w-A}{d-A} \le \frac{1}{1-(C'_{\mathrm{rms}})^2\, d} \tag{4-1}$$

where d is the dimension of the vector space, and C'_{rms} is the worst case average normalized correlation (at zero lag) between an element in one coset and an element in another coset. For the signature sequences derived in this paper, $d = A = N$. This gives:

$$C'_{\mathrm{rms}} \ge 1/\sqrt{N}, \qquad C'_{\mathrm{rms}} \text{ in the range } [-1, 1]. \tag{4-2}$$

It is shown below that the signature sequences derived give elements which meet this bound.

Assuming use of the signature sequences derived, consider two arbitrary elements from two arbitrary cosets. These elements are $N-b$ sequences, denoted $a(k)$ and $b(k)$, which can be expressed as

$$\begin{aligned} a(k) &= wh_i(k)y(k) \\ b(k) &= wh_j(k)x(k) \end{aligned} \tag{4-3}$$

where i and j are independent arbitrary integers from the range [0, $N-1$], indicating the particular sequences within the two cosets. The sequences $y(k)$ and $x(k)$ are the signature sequences, arbitrarily chosen from the $N/2$ different signature sequences available.

The normalized periodic (even) correlation between these two sequences at zero lag, denoted $C'_{a,b}$, is given by

$$\begin{aligned} C'_{a,b} &= \frac{1}{N}\sum_{k=0}^{N-1} a(k)b(k) = \frac{1}{N}\sum_{k=0}^{N-1} wh_i(k)wh_j(k)x(k)y(k) \\ &= \frac{1}{N}\sum_{k=0}^{N-1} wh_{i\oplus j}(k)x(k)y(k) = W\{x(k)y(k)\}(i\oplus j) \end{aligned} \tag{4-4}$$

where $W\{w\}(k)$ denotes the k'th value of the WH transform of sequence w. For the signature sequences constructed, the product sequence $x(k)y(k)$ has a constant amplitude WH transform. Thus the magnitude of the value in (4-4) is independent of i and j.

The constant amplitude WH transform value can be determined from Parseval's relation [2]:

$$\frac{1}{N}\sum_{k=0}^{N-1}[w(k)]^2 = \sum_{k=0}^{N-1}[W\{w\}(k)]^2. \tag{4-5}$$

TABLE I
Example of 16-bit Kerdock Code Set Representatives

representative	sequence
0	0000 0000 0000 0000
1	0011 1010 0101 1111
2	0001 1101 0110 1111
3	0100 1110 0111 0111
4	0010 0111 0111 1011
5	0101 0011 0111 1101
6	0110 1001 0111 1110
7	0111 0100 0011 1111

TABLE II
Definition of GF(8) and the Permutation for each Half Sequence

field element	3-tuple form	old position	new position
0	000	0	0
1	100	1	1
α	010	2	2
α^2	001	3	4
α^3	110	4	3
α^4	011	5	6
α^5	111	6	7
α^6	101	7	5

TABLE III
Resulting Set of 16-bit Signature Sequences

representative	sequence
0	0000 0000 0000 0000
1	0011 1001 0101 1111
2	0001 1110 0111 0111
3	0101 0011 0110 1111
4	0010 0111 0111 1101
5	0100 1101 0111 1110
6	0111 0100 0111 1011
7	0110 1010 0011 1111

Letting $w(k)$ be the product sequence $x(k)y(k)$ and $W\{w\}(k)$ be the WH transform with constant magnitude value $C'_{a,b}$ gives

$$\frac{1}{N}\sum_{k=0}^{N-1} 1 = \sum_{k=0}^{N-1} (C'_{a,b})^2 \tag{4-6}$$

which can be solved to give $|C'_{a,b}| = 1/\sqrt{N}$. Since $a(k)$ and $b(k)$ were arbitrary sequences from arbitrary cosets, $|C'_{a,b}|$ is also the rms cross correlation, as defined in [14]. Thus for the signature sequence set derived, $C'_{\rm rms} = 1/\sqrt{N}$, which meets the bound derived in [14].

V. When N is Odd and/or More Sequences are Needed

When the sequence length, N, is an odd power of two, bent sequences do not exist [19]. However, one can define a "1/2" bent sequence, which has the following properties: 1) the sequence has equal correlation, in magnitude, to half of the WH code words, and 2) the sequence has zero correlation to the remaining WH code words. The WH transform of a half bent sequence gives N transform values: half are $\pm\sqrt{2/N}$, and the other half are zero. This definition can be extended to "1/k" bent sequences, where the sequence is equally correlated, in magnitude, to N/k of the WH code words and not correlated to the remaining code words. When $k = N$, the sequence is a WH code word or its complement (i.e., a $1/N$ bent sequence is a linear sequence).

For N an odd power of two, an optimal signature sequence set would be one in which the product (modulo-2 sum in Boolean) of any two sequences is a half bent sequence. Such a set can be formed from a set of $N' = 2N$ length sequences by dropping the last N bits (i.e., keeping only the left half) of each sequence. This gives a set of N $N-b$ sequences with the property that the product of any two is a half bent sequence.

These results can also be used to form codes. For N an even power of two, the union of each code set ($2N$ biorthogonal code words) formed by the $N/2$ different signature sequences can be viewed as a nonlinear supercode (a Kerdock code) of N^2 code words [10]. For N an odd power of two, the above approach yields a supercode of $2N^2$ code words.

To obtain larger signature sequence sets (or larger supercodes), the requirement that the product (modulo-2 sum) of two signature sequences (i.e., two code words from different code sets) be a bent sequence could be relaxed to require a bent or quarter bent product. For N an odd power of two, this corresponds to products being half bent or eighth bent. The requirement could be further relaxed, incorporating more "grades" of bentness, to obtain even more signature sequences or more code words in a supercode.

VI. Conclusions

An analysis was presented to determine the signature sequence correlation properties desired for a CDMA system using orthogonal coding to spread the signal. An optimal set of $N/2$ signature sequences of length N (N an even power of two) was determined for a direct-sequence CDMA system assuming a) synchronous transmission, b) no multipath time dispersion, and c) orthogonal or biorthogonal WH coding as a means of spreading the information signal. The resulting set of signature sequences consists of the all zero (+1) sequence and $N/2 - 1$ carefully constructed bent sequences. These sequences were formed by permuting code set representatives of a Kerdock code. This set of sequences was shown to meet the extended Welch bound derived by Rowe [14].

For the more general case, when assumptions a) and/or b) are relaxed, the desired correlation properties were shown to be quite numerous. However, the technique of adding a base sequence to all signature sequences may provide some design control in the correlation properties for this case. When the sequence length (N) is an odd power of two, a set of N signature sequences is proposed, which is formed by using the first half of each sequence in a set of $2N$ length signature sequences. By allowing the sum of two signature sequences to have various grades of bentness, larger sets of signature sequences should be obtainable. By forming the union of the code sets generated by each signature sequence, various supercodes of the WH code can be formed.

Research is needed to determine an optimal set of signature sequences designed specifically for an asynchronous, multipath environment in which orthogonal coding is used to spread information signals. Also, methods for generating large sets of signature sequences are needed, whether the sequence length N is an even power of two or an odd power of two.

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